U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-252 932

Cost-Effectiveness Analysis of Municipal Wastewater Reuse

SCS Engineers

Prepared For
Environmental Protection Agency

April 1975

147114

PB 252 932

WATER QUALITY MANAGEMENT GUIDANCE

WPD - 4-76-01

COST-EFFECTIVENESS ANALYSIS OF MUNICIPAL WASTEWATER REUSE

APRIL 1975

WATER PLANNING DIVISION
ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

235

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-440/9-76-005	2.	3. Recipient's Accession No. PB-252 932
4. Title and Subtitle Cost-Effectiveness Analysis of Municipal Wastewater Reuse			5. Report Date May, 1976
			6.
7. Author(s) C.J. Schmidt and D.E. Ross			8. Performing Organization Rept. No.
9. Performing Organization Name and Address S.C.S. Engineers, 4014 Long Beach Blvd, Long Beach, CA 90807			10. Project/Task/Work Unit No.
			11. Contract/Grant No. 68-01-2298
12. Sponsoring Organization Name and Address U.S. Environmental Protection Agency Water Planning Division, (WH-554) 401 M St. SW, Washington, D.C. 20460			13. Type of Report & Period Covered Final
			14.
15. Supplementary Notes			

16. Abstracts

Describes procedures to assist local government agencies in assessing the cost-effectiveness of alternative wastewater reuse systems. The reclamation and reuse of municipal wastewater may often be a technically and economically feasible alternative to disposal of sewage treatment plant effluent. The report inventories existing wastewater reuse sites in the U.S., describes procedures to perform a cost-effectiveness analysis of municipal reuse, applies the procedures developed to two case study locations (Santa Barbara California and Hampton Roads Virginia). Also included is a bibliography of current information on the economics and practice of wastewater reuse.

17. Key Words and Document Analysis. 17a. Descriptors

Sewage disposal (1302)
Sewage treatment (1302)
Water conservation (0203, 1302)
Water reclamation (1302)

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement Release Unlimited	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 235
	20. Security Class (This Page UNCLASSIFIED	22. Price $8.00-2.25

COST-EFFECTIVENESS ANALYSIS OF MUNICIPAL WASTEWATER REUSE

Prepared by

C. J. Schmidt
D. E. Ross

Water Planning Division
Environmental Protection Agency

EPA REVIEW NOTICE

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

1 6 APR 1976

SUBJECT: Cost-Effectiveness Analysis of Municipal Wastewater Reuse

FROM: Mark A. Pisano, Director
Water Planning Division Mark Pisano

TO: All Regional Water Division Directors
All Regional 208 Coordinators

Technical Guidance Memorandum: TECH-2

Purpose:

The enclosed report has been prepared to assist 208 agencies in evaluating the cost-effectiveness of wastewater reuse as a component of a municipal waste treatment system. P.L. 92-500 requires facilities plans to contain an evaluation of wastewater reuse as an alternative waste management technique. Reuse is also to be considered in determining best practicable waste treatment technology for new facilities.

Guidance

This report suggests procedures for evaluating the potential of municipal wastewater reuse. It includes a preliminary test to determine the applicability of reuse to a particular area, cost-effectiveness analysis procedures, and application of the analysis procedures in two case study locations.

Enclosure

cc: State and Areawide Agencies

ic

ABSTRACT

The purpose of this report is to describe procedures to assist local government agencies in properly assessing the cost-effectiveness of alternative wastewater reuse systems. The reclamation and reuse of municipal wastewater may often be a technically and economically feasible alternative to the disposal of all or a portion of an area's sewage treatment plant effluent. However, the reuse option often has not been properly considered in traditional advance planning for wastewater treatment and disposal systems. Use of the procedures described in this report will facilitate the analysis of wastewater reuse options and thus may encourage reuse whenever it is found to be cost-effective.

The report provides the following information:

- A review of existing wastewater reuse sites in the U.S., including an inventory of facilities that provide reclaimed wastewater for industrial, agricultural, recreational, and other purposes.
- A description of procedures for analyzing the cost-effectiveness of alternative wastewater management systems, including wastewater reuse systems. The basic fundamentals of cost-effectiveness analysis are described, and a list of information required for the analysis is presented. Also, a preliminary test is included to help local government agencies determine if wastewater reuse systems are potentially applicable to the area. If reuse is potentially feasible, a complete cost-effectiveness analysis is warranted.
- The application of the cost-effectiveness analytical procedures on two case study locations: The City of Santa Barbara, California, and the Hampton Roads Sanitation District, Virginia. In both cases, no reuse is presently practiced. However, the analyses indicate that wastewater reuse would be cost-effective in both locations as a part of necessary future expansion and modification of sewage treatment and disposal facilities.
- A complete bibliography of current information regarding the economics and practice of wastewater reuse.

TABLE OF CONTENTS

Page

ABSTRACT i

TABLE OF CONTENTS ii

LIST OF TABLES iii

LIST OF FIGURES vi

ACKNOWLEDGEMENTS vii

I. Introduction 1

II. Wastewater Reuse Practice and Pricing Policies 9

III. Preliminary Test: Is Wastewater Reuse a Possibility for Your Area? 25

IV. Background Data Required for Cost-Effectiveness 37

V. Cost-Effectiveness Analysis of Wastewater Reuse Systems 52

VI. Case Study - City of Santa Barbara 66

VII. Case Study - Hampton Roads Sanitation District 93

BIBLIOGRAPHY 116

APPENDICES 166

A. Inventory of Wastewater Reuse Locations in the United States A-2

B. Minimum Water Quality Requirements of Selected Various Water Users B-2

C. ENR Construction Cost Indices 1966-1974 C-1

D. Sample Cost Curves for Estimating Capital and Operating and Maintenance Expenditures for Water Resource Facilities D-1

E. Seven Percent Compound Interest Factors E-1

LIST OF TABLES

		Page
I-1	- Geographical Distribution of Reported Municipal Reuse	4
II-1	- Quality of Effluent Applied to Crops	11
II-2	- Type of Industrial Reuse in the United States	13
II-3	- Effluent Quality vs. User Treatment Required for Cooling Tower Make-Up Water	14
II-4	- Ranges of Effluent Charges for Irrigation Reuse (1972)	19
II-5	- Industrial User Costs for Reclaimed Waste	21
III-1	- Checklist for Determining the Potential Practicality of Wastewater Reuse	26
III-2	- Potential Customers and Uses for Reclaimed Wastewater	30
III-3	- Illustrative Format for Tabulating Data on Potential Customers for Reclaimed Wastewater	34
IV-1	- Information Needed for Economic Analysis of Wastewater Reuse Systems	38
IV-2	- Illustrative Format for Estimating Future Water Use	41
IV-3	- Fresh Water Use Information for Input into Economic Analysis	43
IV-4	- Summary Prices for Reclaimed Municipal Wastewater Including Cost for Procurement and Additional Treatment	46
IV-5	- Quality Parameters for Wastewater Characterization	48

LIST OF TABLES (Continued)

		Page
V-1	- Basic Procedures for Cost-Effectiveness Analysis	53
V-2	- Basic Requirements for EPA's Cost-Effectiveness Guidelines	54
V-3	- Alternative Water Sources and Means of Increasing an Area's Water Supply	56
V-4	- Factors to Quantify in Preliminary Design of Alternative Wastewater Reuse Systems	59
V-5	- Suggested Format for Calculation of Present Values for Alternative Water Supply/Wastewater Treatment Systems	62
V-6	- Suggested Format for Summarizing Present Values of Alternative Water Supply/Wastewater Treatment Systems	61
VI-1	- Population Projection - City of Santa Barbara	69
VI-2	- Present and Projected Water Use and Supply - City of Santa Barbara	70
VI-3	- Characteristics of Santa Barbara's Sewage Treatment Plant	73
VI-4	- Present and Projected Municipal Wastewater Flow Volume - Santa Barbara	73
VI-5	- Average Removal Efficiency of Santa Barbara Sewage Treatment Plant	74
VI-6	- Selected State Wastewater Discharge Requirements Applicable to Santa Barbara	74
VI-7	- Checklist for Determining if Wastewater Reuse is Potentially Practical	76
VI-8	- Potential Wastewater Use in Santa Barbara	77
VI-9	- Costs for Alternative Wastewater Processing Systems	83

LIST OF TABLES (Continued)

Page

VI-10 - Cost for the Cost-Effective Water Supply System Identified for Santa Barbara 84

VI-11 - Calculation of Present Value Costs - Santa Barbara Case Study Alternative 1 86

VI-12 - Calculation of Present Value Costs - Santa Barbara Case Study Alternative 2 88

VI-13 - Calculation of Present Value Costs - Santa Barbara Case Study Alternative 3 90

VII-1 - Service Area Population Data 97

VII-2 - Water Quality Characteristics of Available Potable Water, the York River, and the HRSD's James River Sewage Treatment Plant Effluent 101

VII-3 - Checklist for Determining if Wastewater Reuse is Potentially Practical for HRSD Area 103

VII-4 - Water Use at Yorktown Amoco Refinery 105

VII-5 - Reported Cooling Water Quality for Make-Up Water to Recirculating Systems 106

VII-6 - Quality of Water Used for Boiler Feed at Amoco Refinery 107

VII-7 - Estimated O&M Cost to Amoco for Treatment of Cooling Tower Make-Up 112

VII-8 - Estimated Capital Cost to Amoco for Treatment Facilities for Cooling Tower Make-Up 113

VII-9 - Estimated O&M Cost to Amoco for Treatment of Boiler Feed Make-Up 114

LIST OF FIGURES

Page

I-1 - Renovated Water Uses 3

I-2 - Relative Reuse Volumes in the United States 3

IV-1 - Example Plot of Projected Future Water Supplies and Use 44

VI-1 - Location of Santa Barbara in California 67

VI-2 - The City of Santa Barbara 68

VI-3 - Projected Water Use and Supply From Existing Sources, City of Santa Barbara 71

VI-4 - Alternative 1 - Wastewater Treatment and Effluent Routing 79

VI-5 - Alternative 2 - Wastewater Treatment and Effluent Routing 80

VI-6 - Alternative 3 - Wastewater Treatment and Effluent Routing 81

VII-1 - Hampton Roads Sanitation District Location Map 94

VII-2 - Goodwin Neck Sewage Treatment Plant and Amoco Site Map 95

VII-3 - Projected Water Use in HRSD Case Study Area 99

VII-4 - In-Plant Processing for Upgrading Secondary Effluent for Cooling Tower Make-up Water 109

VII-5 - In-Plant Processing for Upgrading Secondary Effluent for Boiler Feedwater 110

ACKNOWLEDGEMENTS

The assistance of those who contributed their time and effort to this project is gratefully acknowledged. Mr. Gary Broetzman, the initial EPA Project Officer, and his successor, Mr. Stephen Heare, who was EPA Project Officer for the bulk of the project, provided excellent guidance and coordination between SCS Engineers and the Environmental Protection Agency.

Consultant services were provided by Messrs. W. O. Morgan, Ph.D. and Lloyd Mercer, Ph.D., Professors of Economics, University of California, Santa Barbara, California.

Many officials in the city of Santa Barbara cooperated in the preparation of that case study, including the following:

R. W. Puddicomb, P.E., Director of Public Works
Howard Bensen, Assistant Director of Public Works
Charles Evans, Manager, Water Resources Division
Michael Hopkins, Wastewater Treatment Superintendent

Representatives of the Hampton Roads Sanitation District who participated in this study included:

Col. William Love, Director
Gene Goffigon, Director of Treatment

We are also indebted to Messrs. Gene Echols, Chief of Operations, and Jerry Caroll, Chief Engineer, from the American Oil Company's Yorktown Refinery for their close cooperation on the case study work.

CHAPTER I

INTRODUCTION

Community officials have traditionally considered wastewater a liability. Expensive sewer systems are required to collect and transport sewage to a costly treatment plant. Additional facilities are needed to convey the treated sewage to receiving waters or suitable land for disposal. Even after such collection and basic treatment, discharge of poor quality effluent can still occur, causing health and environmental problems.

Now, however, municipal wastewater is being recognized by many communities as a valuable resource. The reclamation and direct reuse of municipal wastewater offer many communities an opportunity to derive various benefits from their former headache. Most importantly, the overall volume of municipal wastes requiring discharge to the local environment is greatly reduced, and the existing water supplies are augmented. Of course, many communities have indirectly reused municipal wastewater for many years by drawing their water supplies from water courses that contain sewage treatment plant effluents from upstream activities. But it is the direct reuse of municipal wastewater that is becoming more attractive for two primary reasons:

1. Regulatory agencies, supported by an environmentally-concerned citizenry, are imposing increasingly stringent standards on sewage treatment plant effluent. Thus, the quality of treated municipal wastewater is being upgraded and is often suitable for industrial and irrigation applications.

2. Population increases in many urban centers are placing an added burden on traditional fresh water supplies. In some parts of the U.S., augmentation of existing fresh water supplies by expanding supply sources, by importation, and/or by groundwater overdrafts is necessary to satisfy water requirements. Such water supply projects are very costly, and local governmental agencies are faced with large expenditures to supply citizens with accustomed volumes of fresh water. In addition, major water augmentation projects may cause significant environmental problems. As an alternate in many locations, reclaimed municipal wastewater is a readily available source of water for non-potable uses to satisfy a portion of the area's demands, thereby delaying water supply projects that may involve greater environmental and economic risks.

Municipal wastewater reuse operations include the categories of:

1. Irrigation
2. Industrial
3. Recreation
4. Domestic

As shown by Figure I-1[1], of the above types of reuse, by far the greatest number of plants practice reuse by irrigation. In terms of volume, however, irrigation reuse accounts for only slightly more than half the reuse reported with industrial reuse a close second. Figure I-2[1] shows the comparative volumes by types of reuse. One large industrial reuser (170 mgd) significantly affects the volume comparison.

Geographically the reuse operations are concentrated in the semi-arid southwestern United States. As shown in Table I-1[1], Texas with 149 municipal reuse operations, and California with 138, reuse wastewater most extensively of all other states.

Research into the engineering aspects of wastewater reuse systems has now advanced the state-of-the-art to a point where such systems are technically feasible for most localities in the United States. Federal law and Environmental Protection Agency policies reflect this advancement and strongly encourage the implementation of municipal wastewater reuse systems whenever such facilities are cost-effective and will result in no greater pollution effects to receiving waters than if reuse were not employed. Thus, the fundamental questions that must be answered by local decision-makers concern costs and benefits: Is there a need for and cost-effective application of wastewater reuse in their water management program, and, if so, what is the most cost-effective wastewater reuse system?

Scope of Study

This report describes the procedures for assessing the cost-effectiveness of wastewater reclamation systems in comparison with conventional wastewater treatment systems. Analyses performed using these procedures are simplified to encourage widespread use by local managers of water supply and/or wastewater treatment agencies.

The methodology is general in nature and is applicable in any locality that desires to investigate the cost-effectiveness of wastewater reuse systems for any or all of the following reasons:

> To supplement water supplies where alternative sources are costly and/or unavailable.

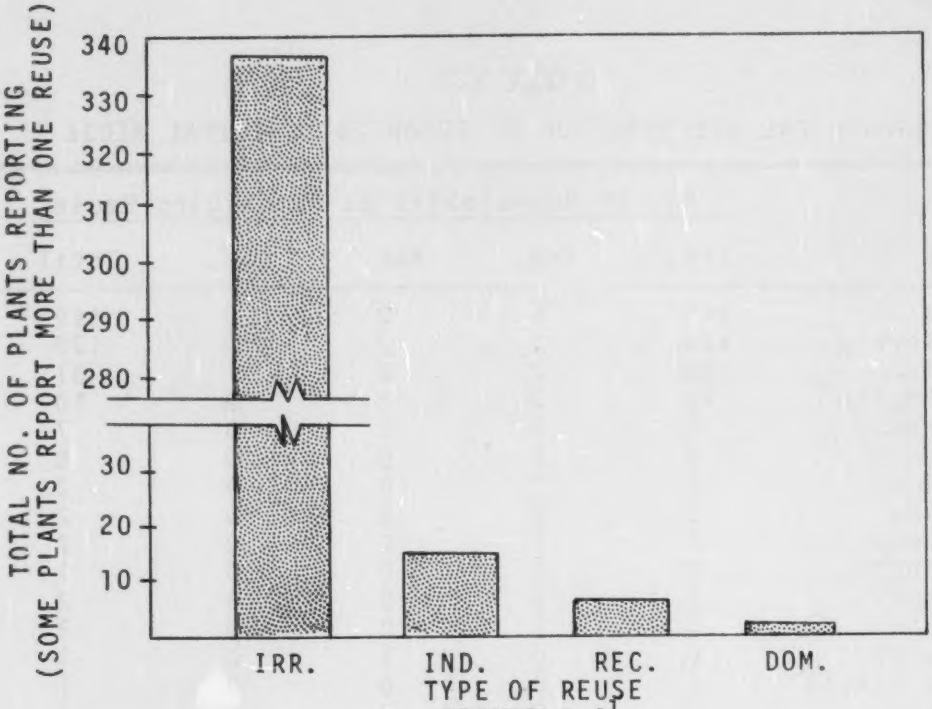


FIGURE I-1[1]
RENOVATED WATER USES

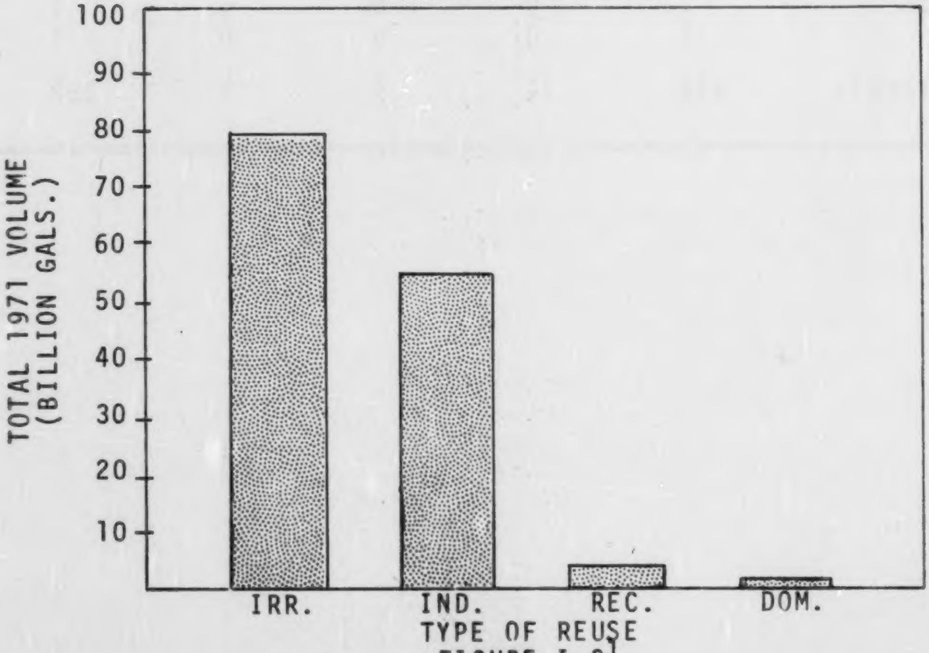


FIGURE I-2[1]
RELATIVE REUSE VOLUMES
IN THE UNITED STATES

TABLE I-1

GEOGRAPHICAL DISTRIBUTION OF REPORTED MUNICIPAL REUSE[1]

State	No. of Municipalities Practicing Reuse				
	Irr.	Ind.	Rec.	Dom.	Total
Texas	144	5	0	0	149
California	134	1	3	0	138
Arizona	28	2	0	1	31
New Mexico	10	0	0	0	10
Colorado	5	1	1	0	7
Nevada	4	2	0	0	6
Michigan	1	1	0	0	2
Florida	2	0	0	0	2
Oklahoma	1	1	0	0	2
Washington	2	0	0	0	2
Missouri	2	0	0	0	2
Maryland	0	1	0	0	1
Kentucky	0	0	1	0	1
North Dakota	1	0	0	0	1
Indiana	1	0	0	0	1
Nebraska	1	0	0	0	1
Oregon	1	0	0	0	1
Utah	1	0	0	0	1
Totals	338	14	5	1	358

- To realize environmental gains.

- To generate revenues from the sale of reclaimed wastewater.

- To reduce the cost of waste treatment (by making higher levels of treatment necessary).

A discussion on cost sharing arrangements between the operator of the sewage treatment system and the users of the reclaimed water is also presented to assist in the implementation of a successful wastewater reuse system.

Use of the evaluation methodology is illustrated by its application in two case studies. Santa Barbara, California, represents a semi-arid area, while Hampton Roads Sanitation District in Yorktown, Virginia, is located where fresh water is relatively plentiful. Neither city now incorporates wastewater reuse facilities into its sewage treatment system.

Cost-Effectiveness Analysis

In the following paragraphs we present a brief description of the type of cost-effectiveness analysis presented in this report. A cost-effectiveness analysis consists of summarizing all the relevant alternatives for accomplishing specific objectives, comparing the total costs of the various alternatives, and selecting the best alternative through the use of appropriate criteria. It should be noted that total costs include environmental and social as well as direct resource costs. However, for the purposes of this study only direct monetary costs are considered.

The basic elements of a cost-effectiveness analysis for wastewater systems include:

1. Stating the problem or problems. Many municipalities have two water problems. First the quantity of fresh water demanded at the prevailing prices either exceeds or soon will exceed the supply capacity of the existing water system. Bringing in additional fresh water can be extremely expensive. Second, the wastewater created whenever fresh water is used must be properly treated and disposed.

2. Defining objectives. The two basic objectives are:
   (a) to meet the community's demand for water, and
   (b) to treat municipal effluent to acceptable standards for disposal or for reuse.

3. Selecting alternatives. The alternatives are the various ways and means of accomplishing the objective or objectives. The alternatives available can be grouped into two general categories:

   a. Use only fresh water from various sources to meet the community's demand for water, and dispose of the wastewater after treating it to acceptable standards.

   b. Treat wastewater to acceptable standards and reuse it along with fresh water from other sources to meet the community's overall water demand. An example would be to apply treated or partially treated wastewater for crop irrigation. Revenues derived from crop sales would go towards reducing overall wastewater treatment costs. A possible third alternative is to reduce the quantity of water demanded by increasing the price of fresh water. Although it is one viable solution,this approach is used infrequently in this country and not considered in this report.

4. Determining costs. Each alternative method of accomplishing the objectives involves certain costs. It is important that all the costs associated with each alternative be considered. For example, it is easy to forget that one of the costs of not using reclaimed wastewater is the expense of bringing in fresh water from new sources to meet the community's demand for water.

5. Establishing a model or models. Models are abstract representations of specific problems which illustrate significant relationships; they aid in predicting the relevant consequences of choosing each alternative. Every water agency in the United States uses models to predict future demands for water,to calculate costs of supplying water, etc. These same types of models can be used in cost-effectiveness analysis for wastewater reuse projects.

6. Designating criteria. A criterion is a test by which alternatives are judged. Criteria subjects for a wastewater reuse system include but are not limited to:

   - Energy consumption
   - System reliability
   - Environmental impact

- Capital costs
- Operating and maintenance costs

Ideally, the best alternative is the one which yields the greatest excess of benefits over cost. Unfortunately, benefits and costs of a wastewater reuse system are sometimes incommensurable. This report approaches the problem by considering only cost of tangibles, as follows:

a. Establish wastewater effluent limitations which must be met, and estimate the future fresh water demands under the present water rates.

b. Select the alternative which meets both the treatment standards and the quantity demands at the lowest possible cost.

Reference Listings

Specific references cited within a chapter are listed at the end of each chapter.

A complete bibliography divided into seven specific categories is included at the end of the report.

CHAPTER I

REFERENCES

1. Schmidt, C. and E. Clements. Demonstrated Technology and Research Needs for Reuse of Municipal Wastewater. Environmental Protection Agency, Washington, D.C. Contract No. 68-03-0148. 1974.

CHAPTER II

WASTEWATER REUSE PRACTICES AND PRICING POLICIES

Present Practices

Many localities in the United States and in other parts of the world are already reclaiming municipal wastewater and providing treatment plant effluent for numerous beneficial uses, such as listed below:

- Irrigation uses, including watering a wide range of agricultural crops, as well as horticulture and landscaping.
- Industrial uses, primarily cooling.
- Recreational lakes.
- Non-potable domestic uses such as lawn irrigation, car washing, and toilet flushing.
- Groundwater recharge.

A compilation of 358 such reuse operations in the U.S. has been obtained from the literature. Pertinent data regarding these operations are summarized according to effluent end use in Appendix A. Information is provided about each facility name and location, the volume of wastewater reused, and the unit charges, if any, received from the sale of effluent. References 1, 2, 3 contain more detailed data concerning both U.S. and foreign reuse activities. A review of these references by those contemplating construction of wastewater reuse facilities is beneficial to learn of others' experiences.

Geographically, reuse operations are concentrated in the semi-arid southwestern United States. Of the 358 areas reporting wastewater reuse practices, 287 are located in Texas and California.

Irrigation Reuse

The most prevalent end use of municipal wastewater is irrigation. In the United States, approximately 340 wastewater plants produce 77 billion gallons of effluent annually which is subsequently utilized for irrigation purposes. Wastewater treatment systems that include land treatment or land disposal are included in this count only if wastewater is intentionally used for irrigation of crops, landscaping, and other such purposes. Thus, approximately 58 percent of the total reuse (by volume) in the U.S. is used for irrigation.

The literature shows a surprising variability in the types of crops being irrigated with municipal wastewater.[4] Successful irrigation of 39 different crops was reported, ranging from turf (grass) for recreation (i.e., golf courses, parks, etc.) at 40 locations, down to sugar beets at three locations. Other crops included truck vegetables, tree fruits, and all types of grains.

The degree of treatment provided prior to irrigation varied greatly from location to location. Roughly three-fourths of the total effluent volume reused for irrigation has undergone secondary treatment. However, primary effluent is still used by some programs for watering corn (for cattle feed), cotton, and pastureland. Fifteen plants provide some type of tertiary treatment of their wastewater before irrigation reuse.

Due to the different degrees of treatment provided, a wide range of effluent quality was reported as being used for irrigation. For example, irrigators of cotton reported BOD's ranging from 15 to 370 mg/l and suspended solids (SS) from 12 to 259 mg/l; grains were watered with effluents varying from 10 to 1,100 mg/l BOD and 10 to 173 mg/l SS. Table II-1 summarizes reported effluent quality as applied to various crops.

Of particular interest are the high average TDS (over 800 mg/l) and Na (over 300 mg/l) levels of reclaimed waters used for irrigation. Excessive TDS in irrigation water can have an osmotic effect, thereby restricting or preventing water uptake by crops because of the increasing salt concentration in the soil. The salts can also be toxic to plant metabolism; and by altering soil structure, permeability, and aeration, they adversely affect plant growth.[5] Yet relatively poor waters in terms of dissolved salts are being successfully used on a wide variety of crops. Proper irrigation management is the key. Consideration must be given to the interrelationships between soil type, crop tolerance, drainage, water application rate, climate, and other factors.

The prevalent relationship between the municipal suppliers of effluent and the users of the effluent for irrigation is to suit the crop to the quality of the effluent. If contaminants are present which are not readily removed by conventional treatment, e.g., TDS and Boron, crops are selected which tolerate the contaminant.

Few of the reuse applications involve irrigation of crops for human consumption. Most of the crops for human consumption

TABLE II-1

QUALITY OF EFFLUENT APPLIED TO CROPS[a]

Crop	No. Plants Irrigating[b]	BOD (mg/1)			SS (mg/1)			TDS (mg/1)		
		Low	High	Avg.	Low	High	Avg.	Low	High	Avg.
Grain	17	10	1,100	180	10	173	71	324	1,400	837
Corn	11	10	370	76	10	135	69	8	1,114	601
Vegetables	6	6	1,100	193	6	127	31	5	1,114	700
Fruit	12	10	160	32	9	135	58	14	1,400	798
Cotton	26	15	370	84	12	259	94	324	2,250	854
Fodder	51	1	370	54	0	259	66	8	1,450	641
Pasture	34	7	370	50	2	118	40	6	2,250	839
Turf & Landscape	47	1	80	19	0	200	26	43	2,000	658

[a] From Reference 6.
[b] Certain plants supply water to more than one crop.

Table II-1 - Continued

Crop	No. Plants Irrigating[b]	Na (mg/l)			Cl (mg/l)			pH		
		Low	High	Avg.	Low	High	Avg.	Low	High	Avg.
Grain	17	87	300	204	10	300	130	6.8	9.9	7.7
Corn	11	56	220	137	49	200	105	6.8	8.7	7.6
Vegetables	6	0	321	163	160	283	212	6.5	9.9	7.5
Fruit	12	100	300	176	115	300	176	7.0	8.4	7.6
Cotton	26	87	450	211	0	460	163	6.7	8.7	7.4
Fodder	51	5	300	167	0	380	154	6.7	8.7	7.2
Pasture	34	10	450	193	2	460	149	6.5	9.2	7.6
Turf and Landscape	47	5	400	140	0	400	109	6.7	9.5	7.4

[b] Certain plants supply water to more than one crop.

are those that do not come into direct contact with effluent such as grapes, citrus, and other tree crops. Truck crops such as asparagus, spinach, and tomatoes are irrigated with reclaimed effluent at only five sites.

Industrial Reuse

A recent survey indicated that reuse of municipal wastewater effluents by industry amounted to 53.5 billion gallons in 1971, or 40 percent of the total United States reuse volume.[6] Only a small percentage of this quantity is consumptive reuse, with over 95 percent utilized for cooling purposes. The bulk of the industrial reuse volume is due to one user, the Bethlehem Steel Plant in Baltimore, Maryland, which utilizes 44 billion gallons annually for once-through cooling.

Only fifteen industrial plants are presently reusing municipal wastewater in the United States. These fifteen facilities include three city-owned power plants, so private industry is represented by only twelve plants in the entire nation. Obviously, numerous potential reuse opportunities remain unrecognized.

Water quality requirements vary widely between industries, between different plants in the same industry, and between various processes within a single plant. The bulk of industrial water is used for cooling, boiler feed, washing, transport of materials, and as an ingredient in the product itself. As shown in Table II-2 cooling is predominant in the reuse of municipal wastewater, accounting for approximately 154 mgd out of the total 156 mgd reported industrial reuse.

TABLE II-2

TYPE OF INDUSTRIAL REUSE IN THE UNITED STATES

Type of Use	Number of Plants	Percent of Total	Reuse Volume (mgd)
Boiler feed	3	17	1
Process	3	17	1
Cooling	12	66	154

Table II-3 shows practice at specific locations in gearing cooling water make-up treatment methods to the quality of the municipal effluent being used. The table indicates that

TABLE II-3

EFFLUENT QUALITY VERSUS USER TREATMENT REQUIRED FOR COOLING TOWER MAKE-UP WATER

	Effluent Quality mg/l			
Selected Users	BOD	SS	TDS	User Treatment Processes
City of Burbank, CA	2	2	500	Shock chlorination, pH adjustment, corrosion inhibitor
Nevada Power Co. Las Vegas, NV	20	20	1,000-1,500	Shock chlorination, lime clarification, pH adjustment, corrosion inhibitor
Southwestern Public Svc. Company Amarillo, TX	10	15	1,400	Lime clarification, pH adjustment, shock chlorination, corrosion inhibitor
City of Denton, TX	30	30	130	Shock chlorination, pH adjustment, corrosion inhibitor (treatment insufficient for effluent of this quality)
El Paso Products Company Odessa, TX	10	13	1,300	Lime clarification, pH adjustment, filtration, softening

superior quality sewage effluents, e.g., the city of Burbank, California, can be used successfully with only an increase in chlorine, acid, and corrosion inhibitors required to put the effluent on almost equal status with fresh water. If, however, the treated sewage effluent is of average quality or worse, then lime clarification treatment is necessary to remove suspended solids and organics prior to use.

Recreational Lake Reuse

There are three major recreational lake reuse projects in the United States, all located in California:

- Santee (San Diego County)
- Lancaster (Los Angeles County)
- Lake Tahoe area

Each of these recreational lake projects has provided important background for advances in wastewater treatment.

The Santee County Water District lakes project is justifiably famous for its pioneering work. Since 1961, the Santee Lakes have been used progressively for recreational activities involving increased human contact as laboratory results and epidemiological information indicated that such activities could be conducted without health hazard. The lakes are now used for boating and fishing with associated activities along the shoreline but are not open for whole-body, water-contact sports. In 1965, an area adjacent to one of the lakes was equipped with a separate flow-through swimming basin which used reclaimed water that was given additional treatment by coagulation, filtration, and chlorination.

The best documented tertiary treatment process in the nation is found at Lake Tahoe, California, where five tertiary treatment steps are combined to provide exceptionally high-quality effluent. Activated sludge effluent is subjected to chemical treatment for phosphate removal, nitrogen removal, filtration, carbon adsorption, and chlorination. This plant also utilizes advanced sludge handling techniques, lime recalcination, and carbon reactivation. The treated effluent is pumped fourteen miles through a lift of 1,460 feet and then flows through gravity pipeline an additional thirteen miles to Indian Creek Reservoir. Indian Creek Reservoir has a capacity of 3,200 acre-feet. It is approved for body-contact sports (swimming) and is reported to have excellent trout fishing.

An interesting project is located at Lancaster, California, where, since 1971, the Sanitation Districts of Los Angeles

County have sold sewage treatment plant effluent to the County of Los Angeles for use in a chain of three recreational lakes. The lakes have a capacity of 80 MG and serve as a focal point for the County's 56-acre Apollo Park. The park, located near Lancaster, was opened to the public in 1973 and features fishing, boating, and picnic areas. Treatment at Lancaster consists of a series of eight oxidation ponds followed by flocculation and sedimentation for removal of phosphates; suspended solids and algae; filtration to polish the effluent; and chlorination.

Each of the three recreational projects briefly described above is unique, but they have much in common. All have found it technically feasible to consistently produce effluent meeting drinking water coliform standards. All practice phosphate removal for algae control and filter the effluent to reduce turbidity. Many species of fish have been grown successfully, including trout.

Domestic Reuse

Great controversy surrounds the subject of domestic reuse of wastewater for potable purposes. Little opposition is voiced to non-potable domestic reuse; e.g., toilet flushing. It is not within the scope of this report to enter into the controversy.

The only current example of direct reuse for domestic purposes in the United States is the non-potable domestic reuse program managed by the National Park Service at Grand Canyon National Park. The Grand Canyon domestic reuse operation provides an average of 30,000 gpd through a separate distribution system for toilet flushing, car washing, irrigation, and construction. Major tertiary treatment given the activated sludge effluent is anthracite filtration and heavy chlorination.

The City of Denver, Colorado, is engaged in a long-term project which is aimed at achieving direct reuse in approximately 1985. The City is operating a pilot facility to test tertiary treatment and accumulate technical and cost data. A significant public education program is also under way.

Groundwater Recharge

Reclaimed municipal effluent is currently being used specifically for groundwater recharge and/or salt water intrusion barriers at ten locations in the U.S. (and also at a few sites in Israel). Several other municipalities across the country practice percolation of effluent solely as a disposal method; these are not included in the following discussion, since the wastewater so disposed has no economic value.

Table A-3 in the Appendix summarizes municipal wastewater recharge locations, purposes of the programs, and volumes recharged.

As shown, the total use of reclaimed wastewater for recharge is currently only 54 mgd (including the Orange County Water District, California, and Oceanside, California, facilities just being completed). All sites provide a minimum of biological secondary treatment, with three programs (Orange County; Nassau County, New York; and the Santa Clara Water District, Palo Alto, California) either constructing or planning extensive tertiary treatment facilities.

Three sites involving tertiary treatment are planning to create salt water intrusion barriers with reclaimed effluent by well injection into groundwater aquifers. These programs are being initiated by the Santa Clara Valley Water District, Palo Alto, California; the Orange County Water District, Fountain Valley, California; and the City of Phoenix, Arizona, in conjunction with the U.S. Department of Agriculture, Agricultural Research Service, Water Conservation Laboratory.

Tertiary treatment is provided at all locations to reduce the chance of groundwater contamination and prevent pore clogging in the injection well. These wells generally have multiple 6-in. diameter casings and are capable of pumping up to 70,000 gpm per well, depending on the capacity of the aquifer. Injection of the high-quality tertiary effluent produces a hydraulic pressure around the well forming a barrier against intruding sea water. Two of the programs (Phoenix and Palo Alto) plan to continue extracting this recharged water for irrigation reuse, while Orange County intends to leave the effluent in the aquifer for replenishment. The other six operations employ percolation as the mechanism to introduce secondary effluent to the groundwater. They take advantage of the soil as an excellent polishing filter to purify the effluent.

Current operations appear to show that recharge with reclaimed effluent can be a sound method of wastewater reuse and conservation of water supplies. However, at this time it is generally accepted that the questions of possible groundwater contamination by virus, pesticides, or residual organics present in reclaimed water have not been sufficiently answered. Whether filtration through soil effectively removes these contaminants and the hazards they present has not been firmly established, although studies are in progress (e.g., Lake George, New York, and Phoenix, Arizona).

A long-range problem facing reclaimed water recharge is potential groundwater degradation due to increasing TDS concentrations. As each use cycle adds an incremental 200-300 mg/l TDS with no subsequent removal, continued recharge and extraction will ultimately degrade the groundwater quality. The extent of this problem will vary from one site to another depending on various factors including the TDS of the groundwater, the TDS of the water supply, and the relative volume of reclaimed water recharged as compared to other recharge volumes (i.e., natural runoff, imported water, etc.).

Pricing Policies

The existing pricing policies for the sale of treated municipal effluent vary greatly depending generally upon one or more of the following factors:

1. Price, availability, and quality of alternate fresh water supplies.
2. The additional cost for transportation, storage, and/or treatment incurred to make the effluent available and suitable for the reuser's purposes. The term "additional" in this context refers to costs over and above what the municipality would normally incur to treat and dispose of its municipal sewage without reuse.
3. Prior water rights held by irrigation users downstream from the municipality may stipulate that volumes of water must be supplied at a certain cost per acre or free of charge.
4. The municipality's attitude regarding the potential value of its treated wastewater. Many municipalities have long considered their wastewater as a liability to be disposed of, and it is difficult for them to now look upon effluent as a potentially valuable asset. For example, only 33 percent of the municipalities canvassed in one study charged a fee to local irrigators for effluent.[6] Of those, the majority charged only nominal fees.
5. Other marketing considerations.
6. Federal or state construction grant fund requirements which stipulate a method for determining the price of effluent for reuse.[7]

As stated above, less than 33 percent of the municipalities presently supplying effluent for reuse sell their product. Most municipalities look upon the irrigation operation, as primarily a means of disposal, and are not prone to demanding payment for effluent which they would otherwise waste. In some cases the irrigation operation allows the municipality to provide only primary treatment; whereas if discharge were made to surface waters, a high degree of secondary treatment would be required.

Treated effluent transportation and storage facilities in many cases may be the largest extra costs to the reuser. The magnitude of the costs is dependent upon many factors, including distance, elevation difference, storage volume, pipe diameter, etc. In some cases, equivalent facilities would be required for fresh water supplies, so no extra cost is incurred for wastewater reuse.

The irrigation reuser is normally less concerned about occasional changes in quality (except health hazards). His only extra cost may be increased volume required to flush out the soil root zone to prevent buildup of TDS, sodium, chlorides, etc. Offsetting this may be the fertilizer value of the effluent, which has been estimated at $18/MG.

Table II-4 shows the range of effluent charges by those suppliers who currently charge for their effluent. The majority of these charge less than $150/MG (approximately $50/acre-ft). Table II-4 does not differentiate between the levels of treatment provided.

TABLE II-4

RANGES OF EFFLUENT CHARGES FOR IRRIGATION REUSE (1972)

Range of Charges for Effluent ($/MG)	Number of Suppliers
< 1	3
1 - 10	14
10 - 25	6
26 - 50	3
51 - 100	5
101 - 150	5
151 - 300	5
301 - 900	0
901 - 1,000	3

Several suppliers charge on either an indirect or flat-rate basis. The typical indirect basis gives the grower all water and land in exchange for a percentage of his farm income, which is, in essence, a sharecropping arrangement. This percentage ranges from 20 to 25 percent.

Flat-rate charges for effluent fall into two categories: token fees and compensatory fees. Token fees are imposed to fulfill legal obligations and protect water rights. Three facilities reported in Reference 6 charge $1.00 per year to users. Compensatory fees are designed to partially defray the costs of treatment. Five other facilities reported in Reference 6 indicated charges in the range of $200 to $1,000 annually. In several cases the price is set by bids received from several interested potential users.

It appears that charges for effluent are primarily influenced by factors other than effluent quality. Among these factors are fresh water cost and its availability in the area, prior water rights in the area, and the municipality's failure to recognize its effluent as a valuable commodity rather than something to be discarded. In actuality the price paid to dispose of wastewater can be considered as a non-zero demand price for the effluent. In all cases, any revenue derived from the sale of effluent is more than that obtained through straight disposal.

The costs to the industrial user of reclaimed water may be divided into two parts: first, the cost of procuring reclaimed water from the municipality, and second, the cost of treating the reclaimed water to make it suitable for the intended use. Table II-5 shows 1972 costs for most of the current industrial reuse operations. In most cases, the additional treatment cost comprises the largest portion of the cost of using reclaimed water by industry. For cooling water used in recirculating systems, treatment costs varied from $100/MG to $550/MG; for water used for boiler feed make-up water use, treatment costs are estimated to be in the range of $500/MG to $1,000/MG.

As with irrigation reuse, the revenue received by municipalities from industrial users of reclaimed water is less than the cost of treatment to the municipality. Since none of the municipalities provide more treatment than would be necessary for discharge to surface waters, any revenues from the sale of wastewater are considered windfall revenues by local taxpayers and government officials.

The main factor which influences the use of wastewater by industry is the procurement and treatment costs of fresh water. Fresh water is like any other economic good--the

TABLE II-5
INDUSTRIAL USER COSTS FOR RECLAIMED WASTE

User	Cost to Procure Effluent ($/MG)	User Treatment Cost ($/MG)	Total Effluent Cost ($/MG)
City of Burbank,[a] California	43	100	143
Bethlehem Steel Corp. Baltimore, Maryland	1.33 (avg.)	N/A[b]	N/A
Dow Chemical Company Midland, Michigan	3.33 (avg.)	N/A	N/A
Nevada Power Company Las Vegas, Nevada	25	193	225
Champlin Refinery Enid, Oklahoma	7	N/A	N/A
Southwestern Public Service Company Amarillo, Texas	80	160	240
Texaco, Inc. Amarillo, Texas	90	194	284
Cosden Oil & Chemical Company Big Spring, Texas	79 (avg.)	742	821
City of Denton,[a] Texas	80	100	180
Southwestern Public Service Company Lubbock, Texas	144	160	304
El Paso Products Company Odessa, Texas	125	550	675

[a] City-owned power plants are considered industrial users in this study.
[b] N/A - Not Available.

higher the price of fresh water, the less fresh water is used and the greater the use of a substitute good, such as wastewater. This fact holds true for domestic use as well as for industrial and irrigation uses. Studies have shown that people do, in fact, reduce their use of potable water as it becomes more costly (References 6, 9-13). Generally, people reduce their use of water outside the house. Lawns are watered less frequently, and cars are not washed as often in areas where water is more expensive than in other areas. It is difficult for people to reduce their use of potable water inside the house, and many studies show that in-house use is reduced much less than outside-the-house use of water. Nevertheless, even uses of potable water inside the house is reduced significantly, and wastewater is substituted for potable water in places where water is extremely expensive. At Grand Canyon National Park wastewater is used for toilet flushing because fresh water is much too expensive to use for this purpose.

In locations where public water supplies are of good quality and available at low cost and/or where the price of water to consumers is in some way subsidized, it is generally considered uneconomical to use reclaimed wastewater. A prospective user would not purchase reclaimed wastewater if fresh water could be cheaply and readily obtained. For this reason, most users of treated wastewater are located in semi-arid parts of the West where fresh water is often rather hard and expensive.

Today, however, the situation throughout the nation is becoming more favorable to wastewater reuse. Fresh water costs are rapidly increasing and the quality of treated sewage is improving, narrowing the cost and quality differences between the competing commodities. The case study described in Chapter VII of this report is an example of the new situation. Where several years ago, the economics of wastewater reuse were not favorable, in 1975 they are.

CHAPTER II
REFERENCES

1. Douglas, James L. and R.R. Lee. Economics of Water Resources Planning. New York, McGraw-Hill Book Company, 1971.

2. Grimo, A.P. Lino. The Impact of Policy Variables on Residential Water Demand and Related Investment Requirement. Water Resources Bulletin. 9(4):703-710, Aug. 1973.

3. Hirshleifer, J.C., DeHaven, and J.W. Milliman. Water Supply: Economics, Technology, and Policy. Chicago, The University of Chicago Press, 1960.

4. Sullivan, Richard H., et al. Survey of Facilities Using Land Application of Wastewater. Environmental Protection Agency, Office of Water Programs Operations, Washington, D.C. Report No. EPA-430/9-73-006. July 1973.

5. Todd, D.K. Groundwater Hydrology, Wiley & Sons, 1959.

6. Schmidt, C.J. and E. Clements. Demonstrated Technology and Research Needs for Reuse of Municipal Wastewater. Environmental Protection Agency, Washington, D.C. Contract No. 68-03-0148. 1974.

7. Grants for Construction of Treatment Works. Federal Water Pollution Control Act Amendments of 1972. 40 CFR Part 35, Subpart E. Federal Register. 39(29): 5252-5270. Feb. 11, 1974.

8. Hanke, Steve H. and R.K. Davis. Demand Management Through Responsive Pricing. Journal of the American Water Works Association. 63(9):550-560, Sept. 1971.

9. Howe, C.W. Water Pricing in Residential Areas. Journal of the American Water Works Association. 60(5), 1968.

10. Howe, C.W. and F.P. Linaweaver, Jr. The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure. Water Resources Research, First Quarter. 3(1):13-32, 1967.

11. Linaweaver, F.P., Jr., C. Geyer, and J.B. Wolff. A Study of Residential Water Use. Department of Housing and Urban Development, Washington, D.C. Report prepared for the Technical Studies Program of the Federal Housing Administration. Feb. 1967.

12. Sullivan, R.H., M. Cohn, and S. Baxter. Survey of Facilities Using Land Application of Wastewater. Environmental Protection Agency, Washington, D.C. Contract No. 68-01-0732. July 1973.

13. Wastewater Treatment and Reuse by Land Application, Volumes I and II. Environmental Protection Agency, Washington, D.C. August 1973.

CHAPTER III

PRELIMINARY TEST: IS WASTEWATER REUSE A POSSIBILITY FOR YOUR AREA?

A complete cost-effectiveness analysis is necessary to determine the feasibility of wastewater reclamation. However, a preliminary review is desirable to roughly determine practicality.

As a general rule wastewater reuse would most likely be cost-effective in those sectors of the country where reuse has been and is now being practiced. Information in Chapter II and Appendix A indicates that reuse is most common in the more arid western and southwestern states, yet there are significant notable exceptions. Wastewater reuse is expectedly more prevalent in areas where precipitation is low, evaporation is high, significant land is irrigated, and where inter-basins transfers of water are now practiced or are planned. However, other conditions affect the cost-effectiveness and feasibility of wastewater reuse systems as well. For example, the Bethlehem Steel Company Plant in Sparrows Point, Maryland, uses large volumes of reclaimed wastewater for cooling even though ample fresh water supplies are available. Also, as the analysis in Chapter VII indicates, wastewater reuse could be attractive in other water rich, non-agricultural areas.

So it is seen that regardless of location in the country, a municipality should investigate the cost-effectiveness of wastewater reuse to determine its potential. After all, site specific conditions are the most important factors and should be explored on an individual basis.

As an aid to local entities,this chapter presents a checklist of conditions that can help determine if wastewater reuse has potential in a specific area. If the checklist evaluation indicates potential practicality, a preliminary survey of the latent market for reclaimed wastewater is warranted. Guidelines for performing the market survey are also provided.

Checklist

A simple test may be employed to indicate the potential practicality of wastewater reuse. The study area should investigate the cost-effectiveness in more detail if one or more of the checklist factors indicated in Table III-1 apply. The relationship of these factors to the practicality of wastewater reuse systems is explained below.

TABLE III-1

CHECKLIST FOR DETERMINING THE POTENTIAL PRACTICALITY OF WASTEWATER REUSE

Wastewater Reuse is potentially practical if one or more of the following factors are true for your area. A more complete analysis should then be performed.

1. Existing or future fresh water supply is limited relative to demand.
2. Existing or future fresh water supply is expensive.
3. The area presently includes or will include individual reusers of large volumes of water.
4. Municipal wastewater that meets high-quality standards is presently discharged for disposal.
5. Requirements for improved wastewater effluent are impending or anticipated.
6. Wastewater disposal is expensive; e.g., a long outfall line is required.

Existing or Future Fresh Water Supply is Limited Relative to Demand. Background data will indicate the existing and projected quantity of fresh water available to the study area from current sources. Similarly, the data will show the current use of fresh water at present prices. Expected water use can be projected based on present consumption factors and anticipated future prices for water. If these data are plotted as shown on Figure IV-1, the adequacy of supply in comparison with demand can be observed at a glance.

In a present or projected shortage situation, where the quantity of fresh water used or expected to be used is greater than the available supply, three basic courses of action or a combination of actions may be taken by the water resource manager.

- Decrease fresh water use
- Increase water supplies
- Reuse wastewater

The most common course of action is to increase the fresh water supply by various means, such as:

1. Further development of local ground and surface water sources.

2. Importation of fresh water from sources outside the local basin.

3. Desalination of brackish or salt water.

Municipalities usually consider development of new in-basin sources and importation first when faced with a water shortage. The technology for such conventional projects is well established,and municipal planners are familiar with alternative means of obtaining water through traditional water resource projects. Costs of these projects are well documented and, therefore, they are not discussed in this report.

Existing or Future Fresh Water Supply is Expensive. It is possible that municipal wastewater could be reclaimed for a cost less than present or projected alternative fresh water supply costs.

Under these conditions, the low-cost reclaimed water could be substituted for low-value uses; e.g., for irrigation and industrial purposes. Equal volumes of fresh water could then be diverted to potable and other high-value uses. This possibility is particularly attractive in areas experiencing water shortages, but it may also be applicable where supply is adequate but where water prices for all uses are considerably high. Of course, wastewater reuse could lessen the stream flow in an area and thereby impose external costs due to the reduction in downstream use opportunities. Such external costs should be considered in the economical analysis of reuse systems.

The Area Presently Includes or Will Include Individual High-Volume Water Users. A significant portion of the cost for reuse systems is attributable to facilities necessary to convey reclaimed wastewater from treatment plants to users. Costs for conveyance can be minimized if there are few customers for the reclaimed water who will use large amounts. The need for extensive distribution systems is thereby eliminated.

Further cost savings will result if large-volume users are located near to and/or at lower elevation than the area's treatment plants. Thus, wastewater reuse systems should be investigated in areas where a significant present or future concentration of demand for high-volume users exist. Users of water for cooling, irrigation, or groundwater recharge, for example, often require large volumes and can use reclaimed effluent.

Municipal Wastewater Meeting High-Quality Standards is Presently Discharged for Disposal. In many parts of the country, municipal wastewater treatment plants now provide secondary or tertiary treatment. The effluent quality from such plants is often suitable for reuse but in general is presently wasted to receiving waters.

The cost-effectiveness of wastewater reuse systems should be evaluated for the study area that currently produces high-quality waste effluent to assure that the potentially valuable effluent is being channeled to its best uses.

Requirements for Improved Wastewater Effluent are Impending or are Anticipated. Whenever an area anticipates an expansion, modernization, and/or improvement in their existing municipal wastewater treatment system to satisfy regulatory requirements, wastewater reuse should be given serious consideration in the planning stages. In fact, existing EPA regulations governing construction grant awards state that municipalities must evaluate the cost-effectiveness of incorporating wastewater reuse facilities into their treatment system plans.

Assessment of Potential Users for Reclaimed Water

In the event that evaluation of the checklist factors indicates the potential desirability of wastewater reuse, it is beneficial to assess the possible market for the sale of reclaimed water. Knowledge of the expected volume and quality demands and the locations of the potential customers will be useful later in formulating alternative treatment plant designs and locations and effluent conveyance systems. Conversely, a preliminary market analysis may indicate that a small amount of the area's reclaimed wastewater would be purchased if it is made available.

A market survey serves as a second preliminary check on the financial feasibility of wastewater reuse. If a market does exist, this information will be useful later for design purposes.

The market survey consists of three basic tasks:

1. The identification of potential customers in the public and private sectors.

2. Preliminary estimate of the potential volume, quality, and reliability of reclaimed water demanded. Consideration should be given to health and legal requirements when applicable.

3. Preliminary determination of effluent treatment, transportation, and storage facilities required.

Identification of Potential Customers

Potential customers can be categorized to facilitate the market survey as follows:

- Governmental users
- Private industrial users
- Private irrigation users

Table III-2 summarizes the possible uses for reclaimed wastewater by these customers. The inventory of wastewater reuse sites (Appendix A) indicates that most of these uses are currently practiced in the United States. The reuse potential for each user class is discussed below.

Governmental Agencies. A municipality should look first at its own activities. Municipal power generation stations, golf courses, parks, school grounds, farms, cemeteries, and recreational lakes are all successfully using treated effluent as a water supply (see Appendix A). In addition, county, state, and federal activities are also excellent prospects to purchase and use reclaimed wastewater. For example, universities, prisons, military bases, etc. are excellent prospects. One university campus may be more economically supplied with reused water than several dispersed primary and secondary schools.

TABLE III-2

POTENTIAL CUSTOMERS AND USES FOR RECLAIMED WASTEWATER

Customer	Uses
Governmental Agencies	Irrigation - Public parks, zoo grounds, government centers, etc. - Public golf courses - School grounds - Publicly-owned farm lands - Right-of-way landscaping
	Groundwater recharge
	Prevention of salt water intrusion
	Recreational lakes
	Public utilities - Cooling water for power plants
	Domestic, non-potable uses - Toilet flushing - Air conditioning
Private Industry	Cooling water
	Boiler feed water
	Process purposes
	Irrigation of grounds
Private Irrigation	Crop irrigation
	Salt leaching
	Irrigation of - Golf courses - Duck clubs - Recreation areas, including artificial lakes

Maintenance of adequate groundwater levels is almost exclusively a governmental function. Local agencies can often beneficially recharge groundwater using reclaimed wastewater together with fresh water. Knowledge of the region's geological, hydrological, and soils features will help determine if proper spreading areas exist in close proximity to the treatment plants.

Landscape irrigation of highway right-of-ways is another possible governmental use for reclaimed water. The costs of facilities needed to deliver the water to such an elongated area may be relatively high, but corresponding costs to irrigate newly developed areas with fresh water would also be high.

In certain cases, it may be feasible to use reclaimed wastewater for domestic non-potable purposes. An example is Grand Canyon Village where a separate piping system conveys reclaimed effluent to homes for toilet flushing, household landscaping, and car washing.

Private Industry. Municipal effluent can be successfully used in essentially all major industrial applications: cooling, boiler feed, and processing, providing no health hazards exist. At present, there are only twelve private industrial reusers of municipal effluent in the nation, and two of these are "company towns" for large copper mines.

Undoubtedly, many opportunities for industrial reuse of reclaimed wastewater are being overlooked especially for cooling purposes. Treated effluent can be successfully used for both once-through and recirculating cooling systems.

Private Irrigation. Private irrigation reuse sales opportunities exist in many areas. Private farms, orchards, and golf courses are all amply represented among existing reusers. Livestock can be safely watered with suitable quality effluent. Essentially all row, field, fruit, and nut crops can be irrigated with reclaimed wastewater, as long as critical quality criteria are met. It is common practice to suit the crop to the quality of the effluent. If contaminants such as TDS and boron are present that are not readily removed by conventional treatment, only contaminant tolerant crops are selected.

Table II-1 summarizes the quality of effluent presently being applied to various crops. A wide quality range is represented; e.g., BOD of 15 to 370 mg/l for cotton, showing that the effluent quality ranges from poor primary to excellent secondary. Of particular interest are the high average TDS (over 800 mg/l) and Na (over 300 mg/l) levels of reclaimed waters used for irrigation. These average values indicate that relatively poor waters in terms of dissolved salts are being successfully used on a wide variety of crops with proper irrigation management.

State health departments generally stipulate the conditions under which wastewater can be used for crops and livestock. Farmers who now purchase reclaimed wastewater generally realize significant cost savings in comparison with fresh water supplies.

Where significant amounts of reclaimed wastewater could be employed for irrigation and a shallow groundwater table exists, there is a possibility that the groundwater underlying the area could become increasingly mineralized due to the percolation of effluent of relatively high salinity. The extent of the problem will depend on several factors including: TDS concentration of the irrigation water, TDS of the groundwater, depth to groundwater, the clay content of the soil, the oxidation-reduction reactions taking place within the soil subsurface, and the pH of the wastewater.

Obviously, the difference between the TDS concentration of the effluent and the groundwater will be a factor in determining the extent of possible degredation. Occasionally, the groundwater is naturally high in salts, and the TDS of irrigation water is not a problem as far as contamination of the aquifer is concerned. Naturally, the reverse is also true; groundwater basins that are low or moderate in salt content may be threatened by heavy irrigation with higher TDS water.

The deeper the groundwater table,the greater the extent of interaction between dissolved solids in the percolating water and soil particles. Clay soils have a greater capacity to adsorb and store metallic ions than more sandy soils. Thus, soil characteristics also determine the potential removals of these ions in the soil profile. Both clayey and sandy soil types show increased abilities to retain heavy metals at pH levels above 7.0[1]

Whether soil conditions are aerobic or anaerobic determine whether metal compounds are in reduced or oxidized forms. In reduced forms metal compounds are soluble and will be leached to the water table. In cases where groundwater degradation may be a problem, an engineering study is necessary before implementing an irrigation reuse system.[2]

Private interests also operate recreational facilities that require significant volumes of water. Private golf courses and country clubs, duck hunting clubs, and recreational lakes are all potential users for reclaimed wastewater and should be screened during the market survey.

All potential customers should be inventoried and tabulated for ready reference. Table III-3 illustrates a format that may be used for this purpose. Potential reusers should be located on a base map of the study area to enable a preliminary determination of pipeline distances to each.

Determination of Volume, Quality, and Reliability Requirements

Each potential customer should be contacted and informed of the reasons for the market study. Information should be solicited concerning the following main topics:

- Volume of water desired, now or in the near future, that could be satisfied by reclaimed wastewater.
- Quality requirements.
- The degree of water supply reliability required to prevent disruption of their activities.

Most potential users will be cooperative and willing to provide the requisite information.

Volume Estimates. For the purposes of a preliminary market survey, the anticipated average daily volume and normal seasonal variations of reclaimed water desired by each potential user should be determined.

Quality Estimates. No single number can characterize the quality demanded by each potential effluent user. It is thus convenient to designate two groups of users to define water quality needs:

1. Those that require only water of a quality that meets the generally accepted minimum standards for the intended use (Appendix B contains tabulations of such minimum standards for most uses of wastewater effluent).
2. Those that require a higher water quality than the generally accepted minimum standards, because their intended use is intolerant to one or more contaminants at those concentrations.

Accordingly, Table III-3 shows that the quality needs of each potential customer will be designated subjectively as:

TABLE III-3

ILLUSTRATIVE FORMAT FOR TABULATING DATA ON POTENTIAL CUSTOMERS FOR RECLAIMED WASTEWATER

Customer Name	Code No.	Average Daily Volume Required[a]	Quality Needs[b]	Reliability Needs[c]	Distance From Stop[d]	Storage Needs[e]
Anytown City Park	I-1	3.0	M	N	2.5	N

[a] Expressed in mdg and (M^3/S)

[b] M - Minimum quality standards for stated purposes.
S - Special quality considerations.

[c] N - Not critical, may be interrupted.
C - Critical, cannot tolerate supply interruption.

[d] Approximate distance in from nearest existing or planned reclamation sewage treatment plant via the most practical route.

[e] N - Storage facilities not required.
R - Storage facilities are required.

- M - minimum quality standards for intended purposes, corresponding to case 1 above, or
- S - special quality considerations, corresponding to case 2.

Degree of Reliability. Most sewage treatment plants experience periodic upsets which could result in temporary interruptions in effluent flow to users. Customers will have differing reliability requirements depending on the intended use of the wastewater and the availability of alternative water supplies. For example, a customer who purchases reclaimed effluent for irrigation may be able to easily tolerate several days interruption in service. Conversely, an industrial user who relies on a constant flow of water to cool a critical process cannot tolerate any reduction in effluent flow unless he has alternate sources of cooling water.

While there are certain degrees between these two extremes, they are suitable for characterizing reliability needs of potential customers for the preliminary market survey. Note that on Table III-3 the letter "N" for non-critical is suggested as a designation for potential users for whom reliability is not a critical factor, while "C" indicates where it is critical. Wastewater storage tanks or ponds could be included in the distribution system to increase reliability of a source when the wastewater stream is not flowing.

Determination of Necessary Effluent Transportation and Storage Facilities. Distances from each potential reuser to the nearest existing and/or proposed sewage treatment plant that will produce wastewater for reclamation can be scaled from a map of the area. The route selected for the measurement should account for topography and possible excavation problems, and may not necessarily be the most direct path. The resultant distance is tabulated as in Table III-3.

In general, potential customers who rely on an uninterrupted flow of wastewater and who do not have alternative water sources will rate an "R" designation for the storage column on Table III-3. "N" signifies that storage facilities are considered unnecessary.

CHAPTER III

REFERENCES

1. Stone, Ralph and J. C. Merrel, Jr. Significance of Minerals in Wastewater. Sewage and Industrial Waste, 30(7), 1958.

2. Evaluation of Land Application Systems. Environmental Protection Agency, Washington, D.C. Technical Bulletin No. EPA-430/9-75-001. March 1975.

CHAPTER IV

BACKGROUND DATA REQUIRED FOR COST-EFFECTIVENESS

Local governmental agencies have available most of the basic information necessary for the cost-effectiveness analysis of potential wastewater reclamation systems. Guidelines on how to prepare a cost-effectiveness analysis, including reference to what data should be included in the analysis, can be found in Guidance for Facilities Planning[1] and the Federal Register Cost-Effectiveness Analysis.[2]

This chapter details data requirements and suggests how and where to obtain them. For the purposes of this report, data needs are classified into three categories:

1. General Background Data
2. Water Use and Supply Information
3. Wastewater Information

Table IV-1 summarizes the information required in all categories. This table is useful as a checklist to assist in the compilation and assembly of the data. The particular data to be gathered and their use in the analysis are discussed in the sections below.

General Background

Knowledge of present and projected future population is necessary for economic feasibility studies of wastewater reuse, since water use projections are based on per capita consumption rates, as discussed later in this chapter. Projected future water use is highly dependent on reliable population projections. However, estimation of future population entails many assumptions and uncertainties. Thus, an area may have various population projections, each derived by different governmental agencies or organizations. Population estimates provided by the local planning agency should generally be used for the initial analysis since water use projections would then be consistent with other planning data.

Land use in the study area influences water consumption and wastewater generation. Local planning agencies are responsible for formulation and maintenance of an area's general plan and would, therefore, be the most direct source of land use information. The general plan usually contains information on both existing and projected land use.

For an analysis of water supply and wastewater disposal systems incorporating wastewater reclamation, the following

TABLE IV-1

INFORMATION NEEDED FOR ECONOMIC ANALYSIS OF WASTEWATER REUSE SYSTEMS

General background information	Possible data sources
Population data . present . projected	. Local and/or state planning or finance agencies. . BEA Series E projections . Local office of U.S. Bureau of Census, Dept. of Commerce
Land use data . present . planned and/or zoned	. Local planning agencies
Topographical base map of study area	
Geological data for study area . soil types and bedrock formations . groundwater depths and locations	. Local office of U.S. Geological Survey . State geological agency . Soil Conservation Service, U.S. Dept. of Agriculture
Climatalogical data for study area . precipitation . evapotranspiration . temperature ranges	. Local flood control agency. . Local airport . Local office of the National Weather Service
Water use and supply information (withdrawal and consumptive)	
Fresh water volume use . present, by category of water user . projected, on basis of existing prices, by category of user	. Local and/or regional agency responsible for water supply. . Local water districts.

TABLE IV-1 (Continued)

Water use and supply information	Possible data sources
Fresh water quality	
. presently supplied . as desired by water users	
Fresh water supplies	
. volume available from various sources throughout planning period . quality of available supplies . reliability of available supplies . water prices - existing - planned increases . costs of water supply system - present - projected	
Wastewater information	. Local and/or regional agency responsible for wastewater treatment and disposal.
Municipal wastewater volume	
. existing . projected	
Municipal wastewater quality	
Location of existing treatment facilities, outfalls, and receiving waters	
Treatment costs for existing system	
. capital . operating and maintenance . expected increases in cost due to more stringent treatment requirements	

general land use categories are typically used:

- Residential
- Commercial
- Industrial
- Agricultural
- Recreational
- Transportation
- Waterways

Knowledge of the location and size of present and projected land use for these purposes is employed in the evaluation of potential customers for reclaimed municipal wastewater. It is beneficial to obtain maps of the study area that indicate the present and projected land use, and to superimpose the locations of existing and planned water supply and wastewater treatment facilities.

If the base maps available do not indicate elevations, a topographical map of the area should also be obtained, since the cost and feasibility of a wastewater reclamation system is influenced by the elevation differences between the sewage treatment plant and potential customers, as well as their respective geographical locations.

Basic information concerning the geology of the study area is useful in the selection of alternative wastewater reuse systems to be evaluated. For example, a groundwater recharge project using reclaimed wastewater could be impractical in an area where the permeability of soil overlying groundwater aquifers is low and/or where geological faults would impede the movement of groundwater from potential wastewater spreading grounds or injection wells.

Geological information of interest includes:

- Location of groundwater basins
- Depths to groundwater
- Type and characteristics of soil in area (permeabilities, alkalinity, and suitability for vegetative growth)
- Type and characteristics of underlying geologic formations

Climatological data, as listed below, are useful in determining an area's water supplies and evaporation losses.

- Precipitation (average annual and frequency throughout the year)
- Average daily temperature ranges for each season
- Evapotranspiration rates

Water Use and Supply Information

Water use information concerning both the quantity and quality of water used is required. In most areas, information regarding the present volume of fresh water used for various purposes is readily available. The volume used may be delineated by user type in areas where meters are installed. Gross water withdrawal and consumption is known in localities that do not meter customers. Future water use projections are also usually available through the agencies responsible for water supply. Projections of future water consumption in the area over a period of at least 20 years are necessary for cost-effectiveness analyses performed for EPA.

If projected water use data are not available, they can be estimated on the basis of existing per capita water use rates and population projections, and/or other applicable unit consumption rates.

Future water use is readily calculated and reported as shown on Table IV-2. Obviously, this calculation does not include major industrial or agricultural users and is dependent on reasonably reliable population projections. Also, consideration should be given to factors that tend to change the per capita use of water, such as changes in the use of water-dependent appliances.[3,4] (It should be noted that water use predicted in this manner is based on the assumption that current prices will remain unchanged over the project period. It is likely that water prices will increase in most localities, resulting in decreased water use.)

TABLE IV-2

ILLUSTRATIVE FORMAT FOR ESTIMATING FUTURE WATER USE

(1) Year	(2) Per Capita Water Use Rate	(3) Projected Population	(4)=(2)x(3) Project Water Use
1974	XX	XXXX	XX
1980	XX	XXXX	XX
1985	XX	XXXX	XX
1990	XX	XXXX	XX
1995	XX	XXXX	XX

Projections based on population are sufficiently accurate for predicting water use in the municipal, residential, and commercial sectors. Other bases of prediction are often desirable for projecting industrial water needs such as unit volume consumed per employee or per unit of production. Future agricultural water use may be estimated on the basis of unit volume used per acre for various types of crop classifications.

If different unit water use rates are utilized, different versions of Table IV-2 are necessary to cover industrial, agricultural, etc. The resulting projected water use volume (Column 4, Table IV-2) from all such tabulations would be summarized in a format as shown in Table IV-3. It is useful to group the various activities into the six main categories shown on Table IV-3 and listed below:

- Domestic (including residential landscaping irrigation)
- Industrial (specifying power generation plants and large industrial complexes)
- Irrigation (including agriculture, golf course, parkland, and municipal horticultural uses)
- Recreational (particularly man-made lakes)
- Groundwater recharge
- Other

Each basic water use category is abbreviated as shown on Table IV-3. It is usually instructive to plot the expected water use versus time, as illustrated by an example on Figure IV-1. When water supply data are similarly plotted, actual or potential shortages are shown.

User's Water Quality Requirements. Water quality requirements of the various water users in the study area should be identified so that the potential for supplying reclaimed wastewater can be assessed. Water quality criteria for various industrial and agricultural uses have been evaluated in the literature. (See Chapter References 5 through 18 for examples.) Appendix B includes a selection of the criteria developed to date for various uses. It should be noted that industrial and agricultural water quality needs may vary significantly from the general limits set forth in Appendix B, depending on local conditions. While the tabulated data may be adequate for a preliminary economic evaluation of wastewater reuse systems, specific quality needs of local industrial processes and agricultural crops must be evaluated for each specific application. Formats similar to those shown in Appendix B can be used in tabulating data on water quality as required by local water users.

TABLE IV-3

FRESH WATER USE INFORMATION FOR INPUT INTO ECONOMIC ANALYSIS

		Daily water use		
Water user class	Present	1980	1990	2000
Domestic (DOM)				
Industrial (IND)				
Irrigation (IRR)				
Recreation (REC)				
Groundwater Recharge (GND)				
Other				
Total				

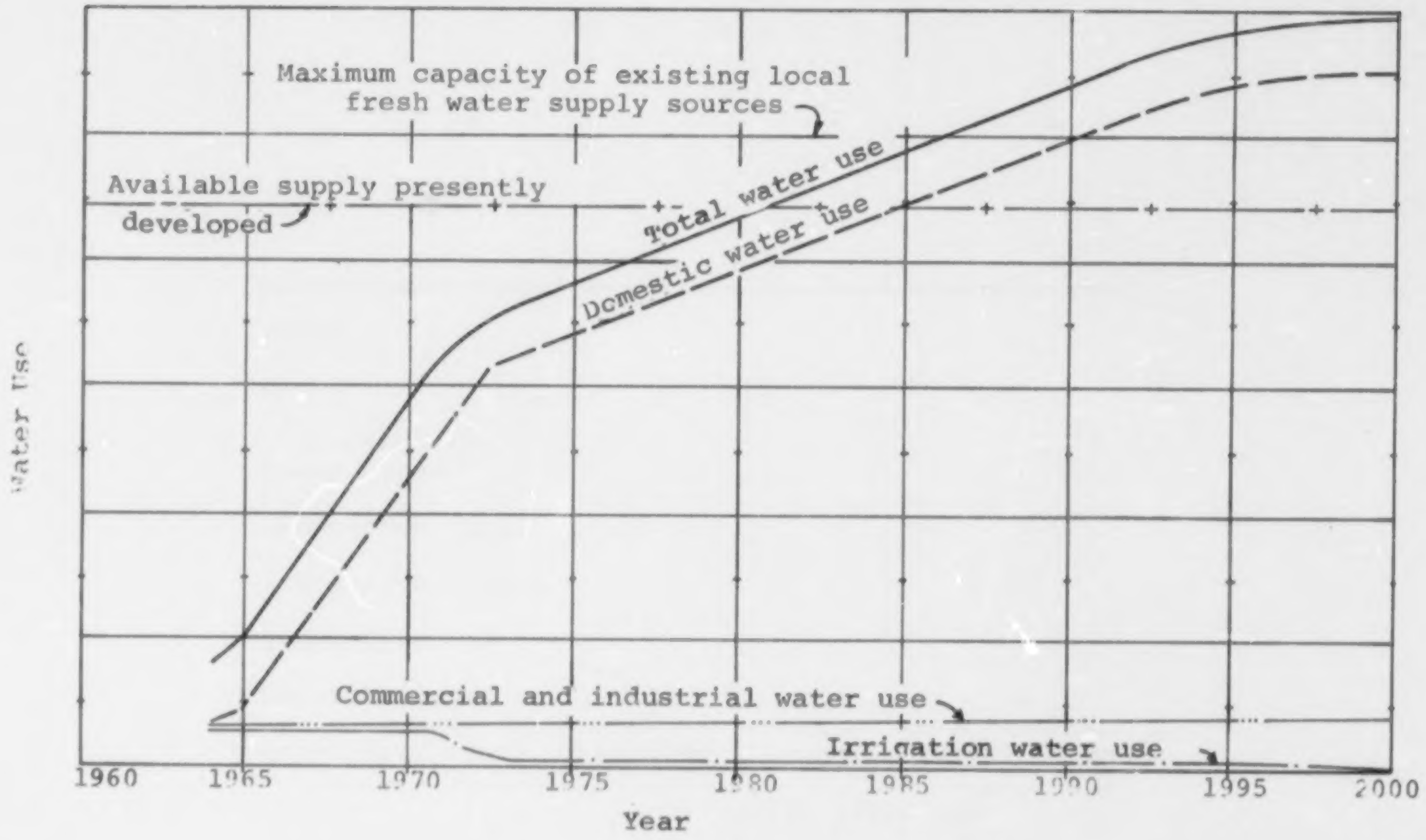


FIGURE IV-1

EXAMPLE PLOT OF PROJECTED FUTURE
WATER SUPPLIES AND USE

Water Supply. Also important in the cost-effectiveness analysis is information concerning fresh water supplies: the volume available from various sources, the quality of each source, the reliability of the supply, and the cost of water from each supply source. These considerations are discussed below.

Data on the monthly variations in fresh water volume available to a locality are usually well defined. The total supply volume may include water from both surface and subsurface sources within the locality's watershed and any water that is imported. Future projections of water supplies can be made on the basis of existing supplies and committed plans for future water resource development programs. The present and projected annual supply volumes can be plotted as illustrated on Figure IV-1. This provides a graphic illustration of anticipated water supplies in relation to projected water use.

The existing and projected quality of alternate water supplies is often an important consideration in the economics of wastewater reuse. Total user costs of reclaimed water are the sum of purchase costs and costs for additional treatment and/or distribution systems required. The potential user, in deciding between alternate water supplies, is interested in what additional treatment and handling costs he must incur, if any, because of quality differences between available fresh water and reclaimed water.

Industrial water users usually require a dependable supply of water to guarantee uninterrupted processing and to avoid costly shut-downs. Agricultural users must have the necessary quantities of water to prevent crop loss. Thus, it is important to consider the volume reliability of the reclaimed wastewater supply since it may differ from that of the fresh water. For example, in any area experiencing a water shortage, domestic needs will normally be met first, with agriculture and industry having lower priority.

The prices of fresh water and reclaimed wastewater are important factors in the analysis of wastewater reuse. In areas where fresh water is inexpensive, wastewater reuse is unattractive. Conversely, in areas where fresh water is expensive, there is more incentive for reuse. Table IV-4 summarizes data regarding the price of reclaimed wastewater reported at existing reuse operations. Note that prices shown include both procurement cost and cost of additional treatment by the user, if any.

Legal or contractual requirements to pay for water supply improvements or to purchase a minimum quantity of imported

TABLE IV-4

SUMMARY OF PRICES FOR RECLAIMED MUNICIPAL WASTEWATER INCLUDING COST OF PROCUREMENT AND ADDITIONAL TREATMENT

Use Use	Range of prices for reclaimed municipal wastewater, $/MG
Irrigation[a]	
Primary effluent	6
Secondary effluent	11
Tertiary effluent	76
Industrial	143 to 675
Recreational	150 to 882
Domestic [b]	1,000 to 1,750

[a] Figures shown are weighted averages based on effluent volume sold by the 20 percent of all municipalities supplying wastewater for irrigational use that actually charge for the effluent.

[b] Reclaimed effluent at Grand Canyon is sold for $1,000/MG where fresh water is available and $1,750/MG where fresh water is unavailable.

water may influence some communities in their consideration of wastewater reuse. Thus, legal factors must be known and incorporated into any economic analysis of wastewater reuse alternatives. Some California areas, for example, are obligated to purchase a minimum quantity of water annually from large water importation projects.

Municipal Wastewater Information

Basic information about an area's municipal wastewater volume, quality, treatment costs, disposal practices, and other factors is essential for the economic analysis, since it is the effluent from the sewage treatment plant that will be used as supply water in a wastewater reuse system. These factors are discussed below.

The volume and quality of the sewage generated by an area to some extent determine what types of reuse applications are feasible and, in addition, influence treatment costs. Wastewater containing contaminants from industrial and municipal activities that are not removed or detoxified by conventional treatment processes may be detrimental for reuse applications. For this reason, many communities that now reclaim municipal wastewater for irrigation have enacted ordinances to prevent the discharge of home water softening recharge wastes (brines) into the sewers. Similar restrictions against the discharge of industrial wastes containing heavy metals are prevalent.

Available wastewater volume and quality data should be obtained. Municipal wastewater volume is generally measured and recorded daily. Likewise, the quality of the raw sewage and existing effluent should be well documented by the local agency responsible for wastewater disposal. Volume data should be reported in terms of average dry weather flow to account for the effects of precipitation. If possible, sewage and effluent quality should be described in terms of all parameters listed on Table IV-5. If available quality data are not so detailed, the most important parameters (designated by an asterisk) should be quantified. Knowledge of the selected wastewater quality parameters can be used in the economic analysis as a preliminary indication of potential wastewater reuse applicability. The location of each existing and planned wastewater treatment facility should be designated on a base map of the study area. The flow expected from each facility should also be noted. This will facilitate the later determination of transport distances from treatment plants to potential wastewater effluent users.

The present cost of wastewater treatment and disposal is usually well documented. This information is useful in estimating the operating, maintenance, and capital cost of

TABLE IV-5

QUALITY PARAMETERS FOR WASTEWATER CHARACTERIZATION

Bacterial:

- Total Coliform [a]
- Fecal Coliform

Organic:

- BOD [a]
- COD

Physical:

- pH [a]
- Turbidity
- Color
- Suspended Solids (SS)[a]
- Floating Solids
- Odor
- Taste
- Temperature

Chemical:

- Total Dissolved Solids (TDS) [a]
- Chlorides [a]
- Fluorides
- Phenols
- Borons
- Nitrates (as NO_3)[a]
- Ammonia Nitrogen [a]
- TKN
- Sodium (% of total cations)

Heavy Metals:

- Aluminum
- Arsenic
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Lithium
- Manganese
- Molybdenum
- Nickel
- Selenium

---

[a] Basic parameters for characterizing municipal wastewater.

the additional effluent discharge pipelines and pumping stations, if any, necessary to transport reclaimed effluent from the treatment plant to potential users.

If wastewater reuse involves a different treatment level than treatment for disposal only, then the operating, maintenance, and capital cost of the various alternative treatment facilities should be estimated.

In some areas, legal and contractual considerations may influence potential implementation of wastewater reuse systems. Such impediments may include:

- Riparian water rights
- Effluent quality standards
- Health Department restrictions

For example, the reuse of wastewater instead of discharge to a receiving stream is complicated by water rights of downstream users. Water rights laws are usually based on a priority system whereby river waters are subject to appropriation. Prior to initiation of a reuse program, such constraints must be investigated and resolved.

A more in-depth investigation of the possibility for implementing a wastewater reuse system can be undertaken once the necessary background data discussed in this chapter has been obtained. The following chapters describe the pertinent analysis.

CHAPTER IV

REFERENCES

1. Guidance for Facilities Planning (2nd ed). Environmental Protection Agency, Washington, D.C., Oct. 1974.

2. Protection of the Environment (Title 40). Appendix A: Cost-Effective Analysis. Federal Register 38(174): 24,639, Sept. 10, 1973.

3. Metcalf, L. Effect of Water Rates and Growth in Population Upon Per Capita Consumption. Journal of the American Water Works Association. pp. 1-21, Jan. 1926.

4. Hanson, R. and H.E. Hudson, Jr. Trends in Residential Water Use. Journal of the American Water Works Association. pp. 1347-1358, Nov. 1956.

5. Bernstein, Leon. Quantitative Assessment of Irrigation Water Quality. American Society for Testing and Materials. (First National Meeting on Water Quality Criteria, Philadelphia, 1966).

6. Culp, Gordon, and A. Selechta. Tertiary Treatment - Lake Tahoe. Bulletin of the California Water Pollution Control Association, January 1967.

7. Day, A.D., T.C. Tucker, and J.L. Strochlein. Effects of Treatment Plant Effluent on Soil Properties. Journal of the Water Pollution Control Federation. 44:373, 1972.

8. Dornbush, James N. and J.R. Anderson. Ducks on the Wastewater Pond. Water and Sewage Works. 3(6), June 1964.

9. McKee, J.E. and H.W. Wolf (ed.). Water Quality Criteria. California State Water Resources Control Board. Publication No. 3-A, 1971.

10. Merrell, John C., Jr., and Paul C. Ward. Virus Control at the Santee, California Project. Journal of the American Water Works Association. February 1968.

11. Parizek, R.R., et al. Penn State Studies Wastewater Renovation and Conservation. Pennsylvania State University Studies No. 23. University Park, Pennsylvania, 1967.

12. Petrasek, Albert C., S.E. Esmond, and H. Wolf. Municipal Wastewater Qualities and Industrial Requirements. (Presented at ASCHE meeting. Washington, D.C. April 1973).

13. Schmidt, Curtis J. The Role of Desalting in Providing High Quality Water for Industrial Use. Office of Saline Water, Washington, D.C. Contract Report No. 14-30-2776. Oct. 1972.

14. Schmidt, Curtis J. and E. Clements. Demonstrated Technology and Research Needs for Reuse of Municipal Wastewater. Environmental Protection Agency, Washington, D.C. Contract No. 68-03-0148. 1974.

15. Water Quality Criteria. Environmental Protection Agency, Washington, D.C. Draft Report. 1973.

16. Water Quality Criteria. Federal Water Pollution Control Agency, Washington, D.C. 1968.

17. Wilcox, Lloyd V. Water Quality from the Standpoint of Irrigation. Journal of the American Water Works Association. 50:650-654, 1958.

18. Williams, Roy E., D.D. Eier, and A.T. Wallace. Feasibility of Reuse of Treated Wastewater for Irrigation, Fertilization and Groundwater Recharge in Idaho. Idaho Bureau of Mines and Geology, Moscow, 1969.

CHAPTER V

COST-EFFECTIVENESS ANALYSIS OF WASTEWATER REUSE SYSTEMS

A cost-effectiveness analysis of wastewater reuse systems is indicated when preliminary investigations, as discussed in Chapter III, suggest the potential practicality of wastewater reuse. Cost-effectiveness analysis provides a rational procedure for determining the best alternative for meeting a community's water supply objectives and the present and future regulatory standards for wastewater disposal.

This chapter describes how to evaluate various water supply alternatives, including wastewater reuse. Table V-1 outlines the basic steps necessary in the evaluation process. Each aspect of the procedures is discussed in the subsequent sections.

Economic studies performed to satisfy EPA requirements must conform to EPA guidelines for cost-effectiveness studies of wastewater treatment programs, as summarized on Table V-2.[1,2] These guidelines have been followed in the case study analyses presented in this report.

Step 1. Determine the Nature and Extent of the Water Resource Problem

During the preliminary analysis (as discussed in Chapter III) the present and projected fresh water use and available supply in the study area will have been assessed. Existing wastewater treatment capacity and future requirements will also have been determined.

When water use is projected to exceed supply, and/or where the level of wastewater treatment is expected to be insufficient to meet EPA standards, the area is faced with a problem.

Step 2. Define Objectives

The municipality must then determine what it will do to solve the predicted shortage in supply and/or the insufficient treatment capability. At a minimum, a municipality's policymakers must establish the following objectives:

- The quantity of water to be supplied
- The water quality for all intended uses
- The minimum quality standards to be met for reclaimed wastewater

TABLE V-1

BASIC PROCEDURES FOR COST-EFFECTIVENESS ANALYSIS

1. Determine the nature and extent of the water resource problem.
2. Define objectives.
3. Hypothesize technically feasible alternatives that can satisfy objectives.
4. Estimate the costs of each alternative.
5. Calculate the present value of each alternative system.
6. Compare the present value of the cost for each alternative which meets or exceeds the objectives. Select that alternative with the lowest value.

TABLE V-2

BASIC REQUIREMENTS OF EPA'S COST-EFFECTIVENESS GUIDELINES[a]

1. Planning period for projects - 20 years.

2. Service lives for each component of a wastewater treatment system.

. Land	Permanent
. Structures	30 to 50 years
. Process equipment	15 to 30 years
. Auxiliary equipment	10 to 15 years

3. Interest (or discount rates)	Water Resources Council Rate

4. Monetary costs shall be calculated in terms of present worth values or equivalent annual values.

5. Interest cost during construction equals the interest rate times the total capital expenditures times one half the construction period in years.

6. The future inflation of wages and prices shall not be considered in the analysis.

---

[a] As presented in 40 CFR 35.

- The extent of the water distribution system

There are many questions to consider in setting program objectives. For example, should all the fresh water that the analysis indicates will be needed in future years actually be provided? Do all water users require the same quality of water, and, if not, should a dual system be considered?

Step 3. Hypothesize Technically Feasible Alternatives that Can Satisfy the Objectives

For any given area there will be several alternative methods of supplying water and of treating municipal wastewater. All technically feasible alternatives must be hypothesized to assure that the cost-effectiveness analysis will point to the least costly system.

The selection of alternatives for evaluation will depend on local conditions. One or more alternatives which do not involve wastewater reuse should be considered. Often, previously completed engineering studies of water and wastewater management for the area will provide a basis for selection of technically feasible conventional alternate systems.

It is helpful to discuss the fresh water supply aspects of a water resources management system separately from the wastewater treatment facilities, although a complete water resource system is comprised of both elements.

Water Supply. Possible sources of water supply available to an area are outlined in Table V-3. Depending on the local conditions, some of these alternative sources are not applicable. Table V-3 also lists several means of increasing an area's water supply.

Expansion of an area's existing water supply system would entail development of one or more of the available sources. The water supply agency must formulate alternative programs that will provide water of sufficient quantity and quality to meet the area's water resource objectives, as established in Step 2 of this procedure.

Wastewater Treatment and Disposal. Municipal wastewater must be treated to prevent environmental degradation. Federal and local regulations set the minimum standards for such treatment; local decision-makers must decide on the specific treatment objectives which may exceed minimum standards.

Water pollution from municipal wastewater can be prevented by various alternative treatment systems, including those that incorporate reclamation and those that do not. In general,

TABLE V-3

ALTERNATIVE WATER SOURCES AND MEANS OF INCREASING AN AREA'S WATER SUPPLY

1. Existing supply sources.
2. Other in-basin sources:
    - Surface waters (e.g., rivers, lakes, reservoirs).
    - Groundwater basins.
3. Imported water from various out-of-basin sources.
4. Wastewater reclamation.
5. Miscellaneous:
    - Water conservation measures (e.g., evaporation controls, improved distribution systems, and drip irrigation).
    - Temporary overdraft of groundwater basins.
    - Weather modification to promote precipitation.
    - Desalination of brackish or sea water.

a wastewater treatment system entails the necessary treatment plant facilities, trunk sewers, effluent conveyance pipelines, and pumping stations required to properly process sewage for disposal.

There are usually several possible alternatives for wastewater treatment. Basically, a locality can construct a system providing secondary or tertiary treatment or a combination of the two if more than one plant is involved. (In rare cases, primary wastewater treatment may be sufficient; however, it is assumed that effluent quality requirements cannot be met by a primary treatment process alone.)

There are numerous unit processes that can be combined to provide the required levels of treatment. In addition, there may be alternative geographical locations for treatment plant siting and different construction phasing possible.

Wastewater Reuse Systems. Development of a technically feasible wastewater reuse alternative or alternatives is based on an analysis of various local factors, such as:

- Location of existing wastewater treatment facility or facilities
- Location of potential effluent customers
- Quality requirements of potential effluent customers
- Volume requirements of potential effluent customers

These and other pertinent factors will have been determined through the market survey, conducted during the preliminary analysis of wastewater reuse applicability (Chapter III).

A preliminary design of a wastewater treatment and reclamation alternative to serve the area could take many forms. For example, it may be very similar to a conventional system, with identically situated treatment plants and sewers, except that means are provided for storage and conveyance of effluent to users. On the other hand, it may involve the construction of one or several satellite treatment plants throughout the area to facilitate reclamation and delivery of effluent to widely scattered customers. Investigation of two or more wastewater reuse plans is beneficial when these alternatives differ widely in terms of treatment plant locations, processes used, customer locations, and timing of treatment plant construction.

Step 4. Estimate the Cost of Each Alternative

Each alternative must be technically feasible to construct and operate. Some degree of preliminary engineering design may be necessary to develop feasible systems that incorporate wastewater reuse. However, the preliminary plans need not be detailed. Table V-4 lists those basic items that should be quantified in the preliminary plans for the purposes of subsequent cost-effectiveness analysis.

The determination of the direct monetary costs for constructing and operating each alternative is one key factor in the analysis. For each alternative to be analyzed, cost estimates should be obtained for the following items:

1. Construction cost of new water resources facilities to be built both at the outset of the project period and at various intervals during the planning period where applicable.

2. Operating and maintenance (O&M) cost on an annual basis. Annual O&M costs may be constant over the project period or they may vary, particularly if new facilities are to be initiated at future dates.

3. Interest costs during construction, as delineated in EPA's guidelines for cost-effectiveness analyses and summarized on Table V-2.[2]

Historical capital costs and their amortization charges should be omitted in all cases. It is the additional cost to be incurred by each alternative system that is relevant to the analysis. Historical capital costs (called sunk costs) have already been committed and must be repaid regardless of which new alternative is adopted.

There are various means possible to estimate the cost of each alternative. Some local agencies will have the expertise, experience, and resources to accurately estimate water supply and sewage treatment plant costs applicable to their particular area. Others can derive pertinent cost estimates developed in recent water supply and wastewater management studies for the service area itself or for neighboring localities. If previously developed cost estimates are used, they must be updated to account for past inflation. The Engineering News Record (ENR) Construction Cost Index is useful for updating past cost estimates to the time of analysis. Cost estimates for water resource projects that were derived in previous years can be adjusted to a present cost basis by applying the ratio of the value of the ENR Construction Cost Index for the year the analysis is performed to the value for the year that the past cost information was developed. Appendix C lists values for the Construction Cost Index from 1966 to July, 1974.

TABLE V-4

FACTORS TO QUANTIFY IN PRELIMINARY DESIGN OF ALTERNATIVE WASTEWATER REUSE SYSTEMS

---

1. Type of treatment process for each plant in the system.
2. Capacity of each plant.
3. Additional sewer requirements, if necessary
    - Size of pipes
    - Length of pipes
4. Effluent discharge facilities required:
    - Length and size of outfall sewers for disposal.
    - Length and size of conveyance pipelines to each potential customer.
    - Pumping needs to supply effluent to upstream users.
    - Storage facilities required, if any, to assure users receive an uninterrupted supply of effluent (e.g., tanks and/or lagoons).

Use of empirically-derived cost data in tabular, graphical, or equation form generally yields acceptably accurate cost estimates for the purposes of a cost-effectiveness analysis. Appendix D provides graphical cost data of a somewhat general nature to assist in the estimation of both construction and O&M costs for water supply and wastewater treatment facilities. However, costs may vary significantly from region to region and from process to process. It is therefore preferable to develop cost estimates on the basis of local conditions and prevailing rates for labor, material, and equipment.

Step 5. Calculate the Present Value of Each Alternative

The costs developed for each alternative in Step 4 cannot be compared directly in that form because of the timing differences in cash flows, and the time variations in the volume of water supplied and wastewater treated by each system. The estimated present value of the costs to be incurred by each alternative over the entire 20-yr planning period must be determined and these costs compared. The general computational procedure to determine the present value of each alternative's costs is as follows:

Present value =

Total capital cost for initial construction and equipment purchases

plus (+)

The capital construction for each subsequent construction phase times the single payment present worth factors based on 7 percent and the number of years from time of analysis

plus (+)

Average annual operation and maintenance cost times uniform series present worth factor based on 7 percent and 20 years (L)

plus (+)

Equipment replacement costs, if service life is less than 20 years based on 7 percent interest and the expected service life value

Minus (-)

Salvage values of equipment and structures times single payment present worth factor based on 7 percent and 20 years, if service life for these items is greater than 20 years.

Table V-5 provides a format useful in calculating the present value of costs for water supply and wastewater treatment system alternatives. Separate tables would be completed for each alternative considered. Applicable present worth factors (pwf) are available in most engineering economics textbooks. A copy of a representative table corresponding to a 7 percent interest rate is included in Appendix E.

For each alternative considered, a total single present value will be calculated, as shown in Column 12 on Table V-5. Present values for all alternatives should be tabulated separately, such as on Table V-6, to facilitate comparisons.

TABLE V-6

SUGGESTED FORMAT FOR SUMMARIZING PRESENT VALUES OF ALTERNATIVE WATER SUPPLY/WASTEWATER TREATMENT SYSTEMS

Alternatives	Present Value of Costs (from Table V-5)
C-1[a]	XXX
C-2	XXX
C-3	XXX
etc.	---
R-1[b]	XXX
R-2	XXX
etc.	---

[a] A conventional alternative which does not reuse wastewater is labeled C.
[b] An alternative which does reuse wastewater is labeled R.

TABLE V-5

SUGGESTED FORMAT FOR CALCULATION OF PRESENT VALUES OF ALTERNATIVE WATER SUPPLY/WASTEWATER TREATMENT SYSTEMS

(1)	(2) Capital and replacement cost, $	(3) Single payment pwf'	(4)=(2)x(3) Present value of capital, $	(5) Annual O&M cost, $	(6) Uniform series pwf'	(7) Single payment pwf' (if applic.)	(8)=(5)x(6)x(7) Present value of O&M costs, $
Start 1975		1.00	XXX	XXX	X	X	XXX
1980		X	XXX	XXX	X	X	XXX
1985		X	XXX	XXX	X	X	XXX
1990		X	XXX	XXX	X	X	XXX
1995		X	XXX	XXX	X	X	XXX
Totals			XXXX				XXXX

Column notes:
(3) pwf' values are given in Appendix E for 7 percent interest.
(5) O&M: operating and maintenance.
(6) pwf values are given in Appendix E for 7 percent interest.

TABLE V-5 (Continued)

Year	(9) Salvage value of equipment and structures, $	(10) Single payment pwf'	(11)=(9)x(10) Present value of salvage, $	(12) Total present value - columns (4)+(8)-(11)=(12)
1975	XXX	X	XX	XXX
1980	XXX	X	XX	XXX
1985	XXX	X	XX	XXX
1990	XXX	X	XX	XXX
1995	XXX	X	XX	XXX
Totals			XXX	XXXX

Step 6. Compare the Present Value of the Cost for Each Alternative

The foregoing analysis will indicate which alternative has the lowest present value for cost over the 20-yr period. This lowest cost alternative may or may not employ wastewater reuse, but it must be chosen as the cost-effective alternative.

It must be recognized that the cost-effectiveness analysis is based on indefinite information: predicted population data; projected fresh water demands; estimated facilities costs; and various other assumptions. If time and resources allow, it is useful to recalculate the costs of each alternative based on different assumptions, particularly if two or more alternatives have approximately equal costs. The results of a series of recalculations will indicate the sensitivity of the results to possible changes in important factors such as projected wastewater volume sold for reuse, construction cost estimates, and estimated fresh water use.

The cost-effectiveness methodology can be a useful tool in assisting local agencies to evaluate the best alternative water supply/wastewater treatment system. Its use encourages the consideration of wastewater reuse systems where they are economical and/or environmentally beneficial. But if reclamation systems are not cost-effective and/or do not enhance the local and regional environment, they should not be constructed.

The foregoing analysis procedure is based strictly upon economic considerations in terms of monetary costs only. It is recognized, however, that other factors such as energy use, social effects, environmental impact, reliability, public acceptability, and so forth can and should significantly influence decision-makers.

CHAPTER V

REFERENCES

1. Guidance for Facilities Planning (2nd edition). Environmental Protection Agency, Washington, D.C., October, 1974.

2. Protection of the Environment (Title 40). Appendix A: Cost-Effective Analysis. Federal Register. 38(174):24,639, Sept. 10, 1973.

CHAPTER VI

CASE STUDY - CITY OF SANTA BARBARA

Procedures described in Chapter V for determining the cost-effectiveness of alternative wastewater reuse systems are applied in this and the following chapter to two case study situations: Santa Barbara, California, and Hampton Roads Sanitation District, Virginia. These case studies represent two distinct areas where wastewater reuse may be considered. The Santa Barbara area is a semi-arid region with essentially no major industrial water users. In the Hampton Roads area, however, relatively abundant fresh water is available, and there are heavy industries nearby that use large volumes of water. Results of the case study analyses show that selective wastewater reuse can be cost-effective in both situations.

The city of Santa Barbara is located on the south coast of California, approximately 80 miles northwest of Los Angeles. Figure VI-1 shows the area's location in relation to California's major cities. Figure VI-2 provides a map of the general area. Santa Barbara is in a semi-arid region and will soon face a water problem since the projected consumption of water will be greater than the projected supply of water from the present sources.

At present, the city obtains its water from wells and from the Cachuma and Gibraltar Reservoirs, both fed by the Santa Ynez River. In the future, fresh water from Northern California may be available to Santa Barbara through a coastal branch of the California State Water Project. However, this supplementary source of water would be rather expensive. Consequently, city officials have expressed considerable interest in using reclaimed wastewater as one supplementary water source and have commissioned various studies of the situation in the past.[1,2] The existence of a complete, up-to-date data base makes the city of Santa Barbara an ideal case study to illustrate the use of the procedures for determining the cost-effectiveness of wastewater reuse.

Background Data

A cost-effectiveness analysis is dependent on the availability of basic information concerning an area's water resources, as discussed in Chapter IV. Accordingly, pertinent information on Santa Barbara's fresh water supply and demand, wastewater characteristics, and other factors has been obtained and is summarized below.

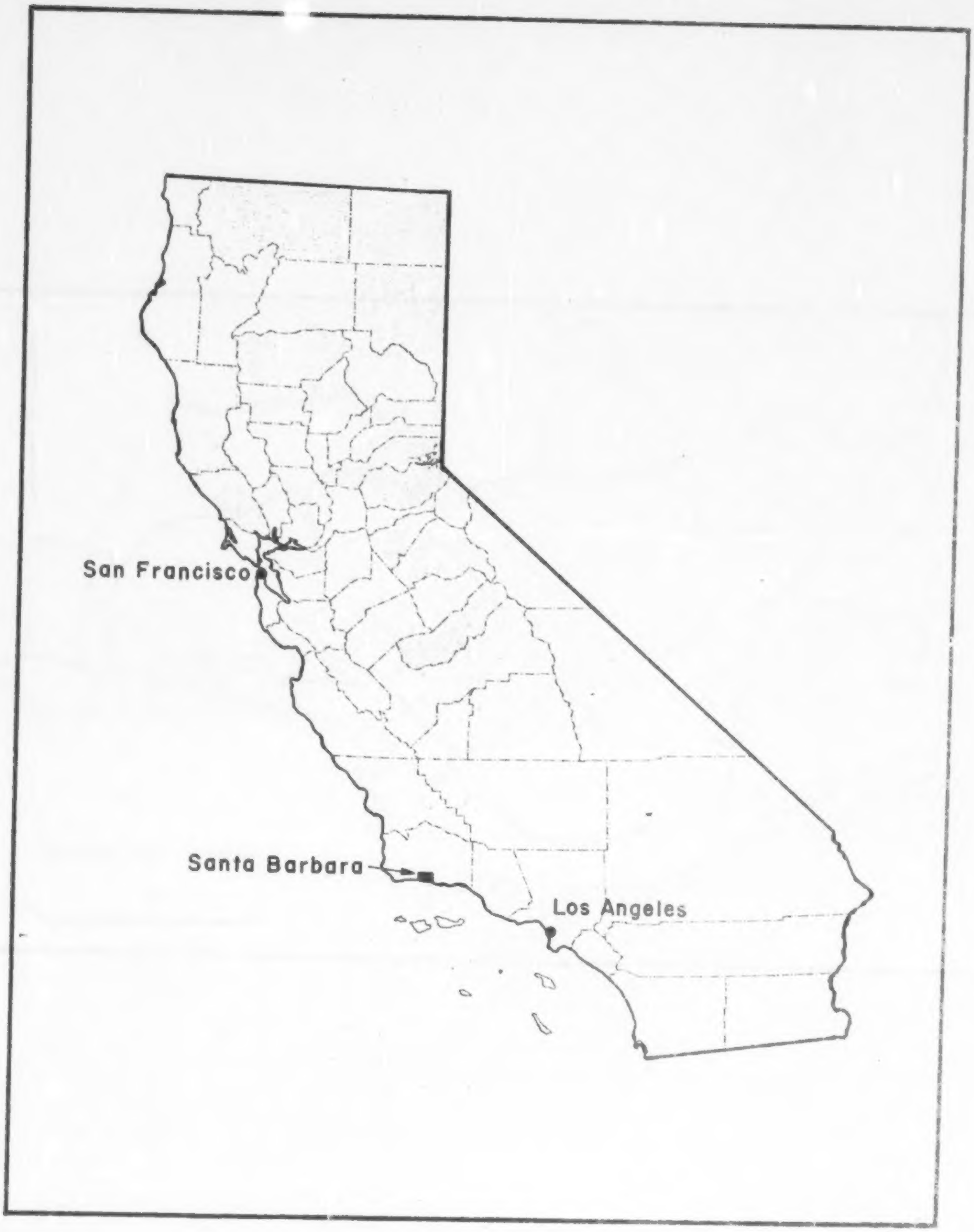

San Francisco
Santa Barbara
Los Angeles

FIGURE VI-1

LOCATION OF SANTA BARBARA IN CALIFORNIA

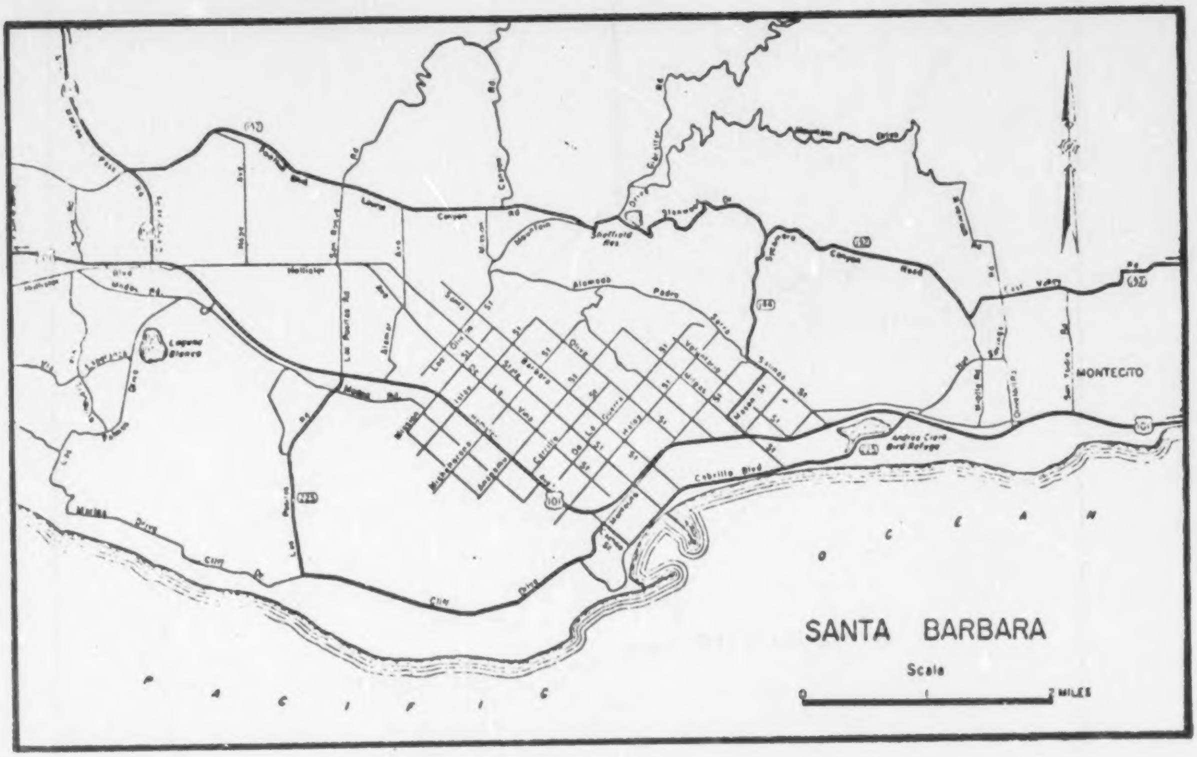

SANTA BARBARA
Scale
0
1
2 MILES
MONTECITO
P A C I F I C
O C E A N
Cabrillo Blvd
Cliff Drive
Andree Clark Bird Refuge
Laguna Blanca
Sheffield Res
101

FIGURE VI-2

THE CITY OF SANTA BARBARA

Geological and Topographical Data. Santa Barbara is located in a low lying plain surrounded by the adjacent foothills of the Santa Ynez Mountains to the north. These mountains stand between the city and the two reservoirs from which the city obtains part of its water supply.

The area has several geological faults which tend to impede the underground flow of groundwater. These faults also make it more costly to recharge the groundwater basins below the city. There are two levels of groundwater under Santa Barbara - one is 250 feet below sea level, and the other is about 375 feet below sea level. The calculated capacity of both levels is approximately 60,000 MG. The estimated safe yield of this groundwater basin is 1.79 mgd.

Climate. Santa Barbara receives 95 percent of its 18 inch annual rainfall between November and May. The average winter temperature is 55°F, and the average summer temperature is 65°F. The mornings are generally foggy during the summer, but offshore winds usually dissipate the fog by midday.

Population. Various population projections for the city of Santa Barbara are available, each based on differing expected growth trends ranging from an assumed low net growth rate (zero growth after 1990), up to an optimistic net growth rate of 2.8 percent a year. In this case study, a net growth rate of 1.25 percent per year is used as a basis for predicting water use as tabulated on Table VI-1.

TABLE VI-1

POPULATION PROJECTION - CITY OF SANTA BARBARA

Year	Population[a]
1973	72,400
1980	81,300
1990	93,900
2000	103,700

[a] Corresponds to projection B in Ref. 1.

In using this population projection, future projected demand for water, if in error, would tend to overestimate future water use. It should be noted that Series E population projection estimates are specified for use in California unless specific studies indicate differing projections.

Land Use. Land in Santa Barbara is used mainly for low density residential housing. There is practically no heavy manufacturing or heavy industry in Santa Barbara, and it is expected that this will continue to be the case. Any industrial growth in the city is expected to be in light production (e.g., electronics) and research and development. Agricultural land use is expected to continue to decline, and residential land use is expected to take its place. A significant area is devoted to parks, golf courses, bird sanctuaries, and other vegetated open space land uses.

Fresh Water Considerations

Water use in Santa Barbara in 1973 was approximately 13 mgd. By the year 2000, 20 mgd will be used according to city projections. However, the safe firm yield capacity of the existing water supply system is expected to decrease from the present 13 mgd down to 11 mgd in the year 2000, as indicated on Table VI-2.

TABLE VI-2

PRESENT AND PROJECTED WATER USE AND SUPPLY - CITY OF SANTA BARBARA[1]

Year	Water Use mgd	Firm Yield Water Supply From Existing Sources mgd	Difference Supply-Use mgd
1973	13.2	13.4	0.2
1980	15.3	13.4	(2.0)
1990	18.1	12.7	(5.4)
2000	20.0	11.3	(8.7)

(The expected decrease is due primarily to siltation of reservoirs.) Figure VI-3 shows that if the projected demand for water at the present water rates through the year 2000 is to be satisfied, Santa Barbara will soon have to establish

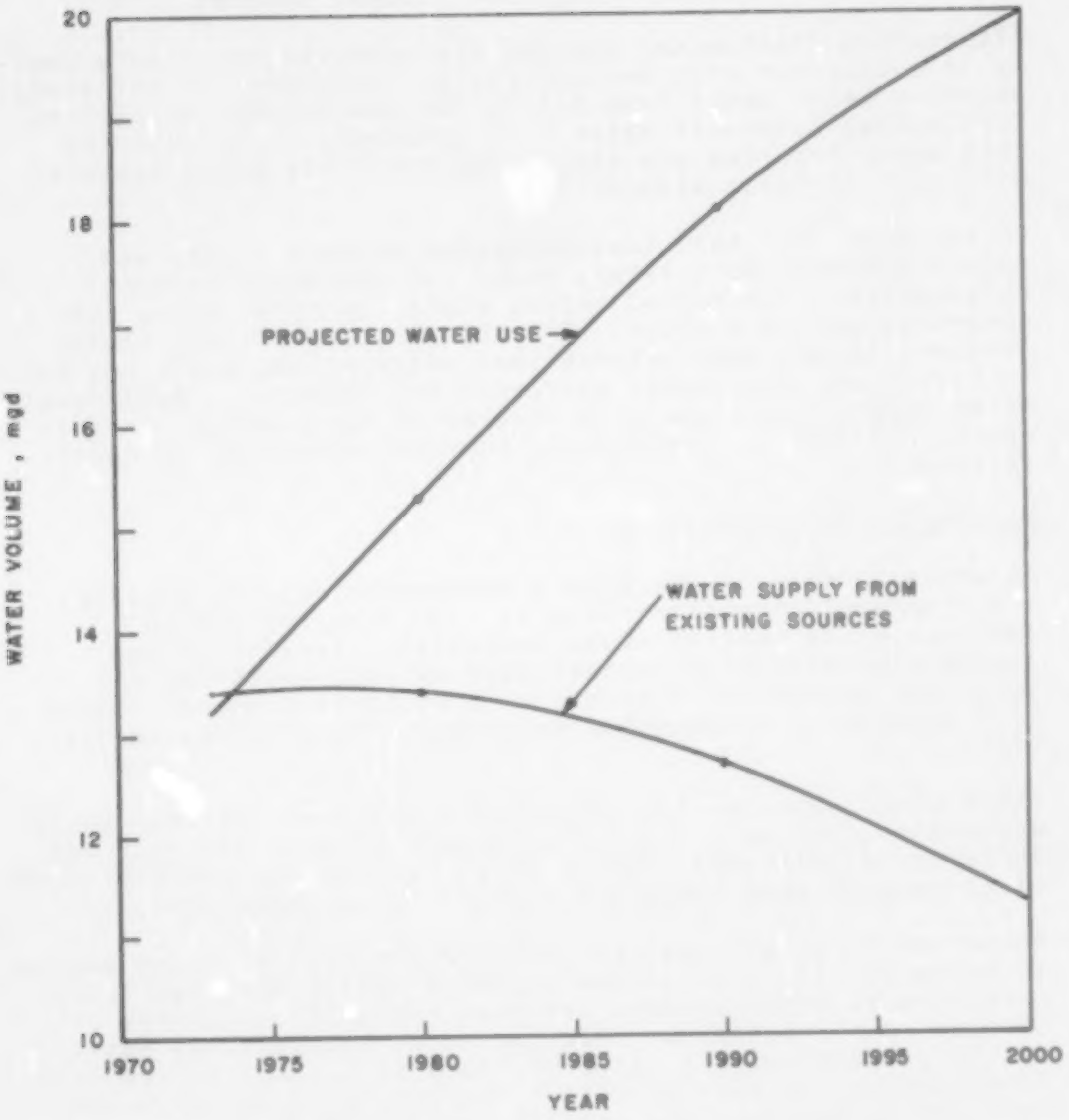


FIGURE VI-3

PROJECTED WATER USE AND SUPPLY FROM EXISTING SOURCES
CITY OF SANTA BARBARA

(Derived from data in Ref. 1)

a supplementary water supply capable of providing 9 mgd in addition to the amount drawn from present sources.

Alternative fresh water sources are expected to be very costly in comparison with present costs. According to one study, existing water costs from $77/MG for groundwater to $107/MG for Cachuma Reservoir water. In contrast, it is expected that water imported via the California State Water Project will cost at least $630/MG.[2]

It is recognized that implementation of more costly water supply systems could likely result in increased consumer water prices. Increased prices would, in turn, cause consumers to use less water. For the purposes of this study, however, it has been assumed that water prices would not be increased and that water use would not decrease. Additional water supply costs would be covered by tax revenues in this event, a financing arrangement commonly practiced by municipalities.

Wastewater Considerations

An understanding of the area's wastewater volume, quality, and treatment characteristics is also required for an analysis of wastewater reuse potential. Presently, one sewage treatment plant constructed in 1951 processes all municipal wastewater from the city of Santa Barbara. Table VI-3 summarizes information describing the existing facilities.

Table VI-4 indicates the projected average dry weather wastewater flow that will require treatment through the year 2000. Influent and effluent quality of wastewater and the treatment plant removal efficiency are summarized on Table VI-5.

Requirements promulgated by California's Central Coast Regional Water Quality Control Board (RWQCB) stipulate that Santa Barbara must provide added treatment for all wastewater discharged to the ocean, as illustrated by the selected waste discharge requirements shown on Table VI-6. Hence, the city is expanding its existing plant to provide secondary treatment and to increase the capacity to 11 mgd.

Faced with the prospect of high-cost water in the future, Santa Barbara understandably desired a more thorough analysis of its water supply alternatives. At the same time, wastewater treatment requirements were becoming more stringent, and their treatment plant was nearing capacity. Consequently, the reclamation of wastewater to help solve both a water supply and sewage treatment problem offered a promising course of action to the city.

TABLE VI-3

CHARACTERISTICS OF SANTA BARBARA'S SEWAGE TREATMENT PLANT[1]

Design Capacity	8.0 mgd
Existing flow	7.5 mgd
Degree of treatment	primary
Ocean outfall	
Length	3,400 ft
Diameter	42 in.

TABLE VI-4

PRESENT AND PROJECTED MUNICIPAL WASTEWATER FLOW VOLUME - SANTA BARBARA[1]

	Average Dry Weather Flow	
Year	mgd	acre-ft/yr
1973	7.5	8,400
1980	9.3	10,400
1990	11.7	13,100
2000	14.2	15,900

TABLE VI-5

AVERAGE REMOVAL EFFICIENCY OF THE SANTA BARBARA SEWAGE TREATMENT PLANT[1]

	BOD	Suspended Solids (SS)
Average influent (mg/l)	207[a]	192
Average effluent (mg/l)	141	93
Average percent removal	32	52

[a] Based on data collected in May, June, July, and August, 1974.

TABLE VI-6

SELECTED STATE WASTEWATER DISCHARGE REQUIREMENTS APPLICABLE TO SANTA BARBARA

	State Ocean Plan Requirement[a] (mg/l)	
Constituent	50 percentile	90 percentile
BOD	a	b
Suspended Solids	50.0	75.0
Settleable Solids	0.1	0.2

[a] Based on statistical variation; e.g., the 90 percentile means that the specified concentration must not be exceeded 90 percent of the time.

[b] Standard not specified.

Preliminary Test: Is Wastewater Reuse a Possibility for Santa Barbara?

A review of the checklist for determining if wastewater reuse is potentially practical for an area (Table VI-7) shows that Santa Barbara exhibits all five positive conditions:

1. The existing and future supply of inexpensive water is limited and is expected to decline.
2. Supplementary fresh water from the California State Water Project will be very expensive (about six times more costly than water from Santa Barbara's present sources).
3. Irrigation of agriculture land, parks, golf courses, and other open space with reclaimed wastewater is a distinct possibility. The quantity of wastewater treated (and projected to be treated) in Santa Barbara is much larger than the projected shortage of fresh water during the 20-year planning period, as observed by comparing data on Tables VI-2 and VI-4.
4. Municipal wastewater of relatively high quality will soon be discharged for disposal once the planned secondary treatment facilities are built. (Santa Barbara has already responded to the state-imposed effluent quality regulations by initiating work on a new sewage treatment plant. Therefore, item 5 of the checklist is a moot point in this case.

It is clear, then, that wastewater reuse is definitely a possibility for Santa Barbara. A study of the potential market for wastewater sales is justified.

Potential uses of reclaimed wastewater in Santa Barbara are for irrigation and groundwater recharge, as indicated on Table VI-8. An estimated 2 mgd of wastewater could be substituted for fresh water to irrigate city parks and other open space. There is essentially no demand for industrial cooling water, since there is no heavy industry in the city.

Use of reclaimed wastewater for groundwater recharge would be accomplished by injection since insufficient suitable area is available within the city limits for surface spreading and percolation. Well injection of wastewater into potable groundwater is presently prohibited by California State Department of Public Health Standards.

TABLE VI-7

CHECKLIST FOR DETERMINING IF WASTEWATER REUSE IS POTENTIALLY PRACTICAL

Wastewater reuse is potentially practical if one or more of the following factors are true for your area. A more complete economic analysis should then be performed.

☑ 1. Existing or future fresh water supply is limited

☑ 2. Existing or future fresh water supply is relatively expensive

☑ 3. The area presently includes or will include individual entities who use high volumes of water

☑ 4. Municipal wastewater of relatively high quality is presently discharged for disposal

☑ 5. Requirements for improved wastewater effluent are impending or are anticipated

TABLE VI-8

POTENTIAL WASTEWATER USES IN SANTA BARBARA

Use	Volume (mgd)[1]	Quality req.[a]	Reliability[b]	Storage req.[c]
City golf course	0.36	M	N	N
Las Positas Park	0.36	M	N	N
Hope Ranch Country Club	0.36	M	N	N
Oak Park	0.10	M	N	N
Earl Warren Park	0.11	M	N	N
U.S. Highway 101	0.01	M	N	N
Seaside Park	0.75	M	N	N
Irrigation use, Total	2.05			
Groundwater Injection	d	S	N	N

[a] Quality requirements: M - minimum acceptable for wastewater
S - special standards for groundwater injection

[b] Reliability: N - not critical for user

[c] Storage requirement: R - required to assure adequate flow throughout the year
N - not required to assure adequate flow

[d] Prior to 1987, wastewater cannot be injected according to state law. For the purposes of this study, it is assumed that wastewater injection into the groundwater will not be practiced during the 20-year planning period.

Cost-Effectiveness Analysis of Wastewater Reuse for Santa Barbara

Three alternative wastewater treatment and effluent routing schemes are considered for this analysis as described below. Figures VI-4, VI-5, and VI-6 refer to Alternatives 1, 2, and 3, respectively.

- Alternative 1 - No reuse is practiced. A 16 mgd sewage treatment plant would be constructed adjacent to the existing plant, and effluent would be discharged to the Pacific Ocean.

- Alternative 2 - A total of 2 mgd of effluent is reclaimed for irrigation of parks and other open space in Santa Barbara. A 16 mgd central sewage treatment plant is constructed adjacent to the existing site, as in Alternative 1. To convey effluent to the reuse locations, Santa Barbara must construct an effluent pipeline system and pumping facilities.

- Alternative 3 - A 12 mgd central sewage treatment plant would be constructed adjacent to the existing plant. In addition, a 2.6 mgd satellite plant would be constructed at Mission Creek. Also, Santa Barbara would support the expansion of the existing plant at Montecito to 1.6 mgd and would install effluent pipelines to coastal irrigation sites. Effluent from the satellite and Montecito facilities would be routed to the nearest areas that can use reclaimed water for irrigation. As in Alternative 2, 2.05 mgd would be reclaimed. Unreclaimed effluent from the satellite plant and all effluent from the central plant would be discharged to the ocean through the central plant outfall.

Other alternative systems are theoretically possible, but the three selected represent the most feasible at this time. For example, groundwater recharge by well injection is a possibility for Santa Barbara. However, existing state health laws prohibit the direct injection of reclaimed wastewater into potable groundwaters. It is anticipated that this ban will be relaxed within the next ten years if and when long-term test results and improved treatment levels can guarantee safe injection practices. For the purposes of this illustrative case study, it has been assumed that Santa Barbara would not be able to directly inject wastewater for recharge purposes within the 20-year planning period. (It should be noted that groundwater recharge with effluent by surface spreading

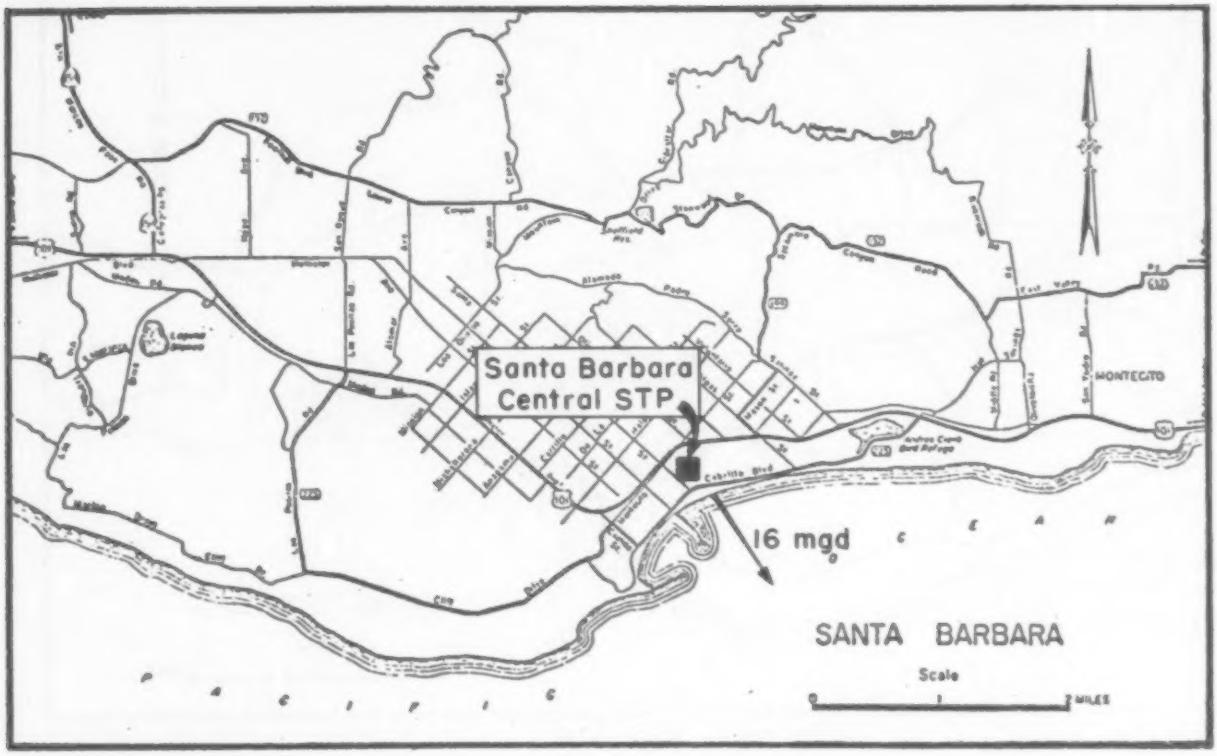

Santa Barbara
Central STP
16 mgd
MONTECITO
O C E A N
P A C I F I C
SANTA BARBARA
Scale
0
1
2 MILES

FIGURE VI-4

ALTERNATIVE 1
WASTEWATER TREATMENT AND EFFLUENT ROUTING

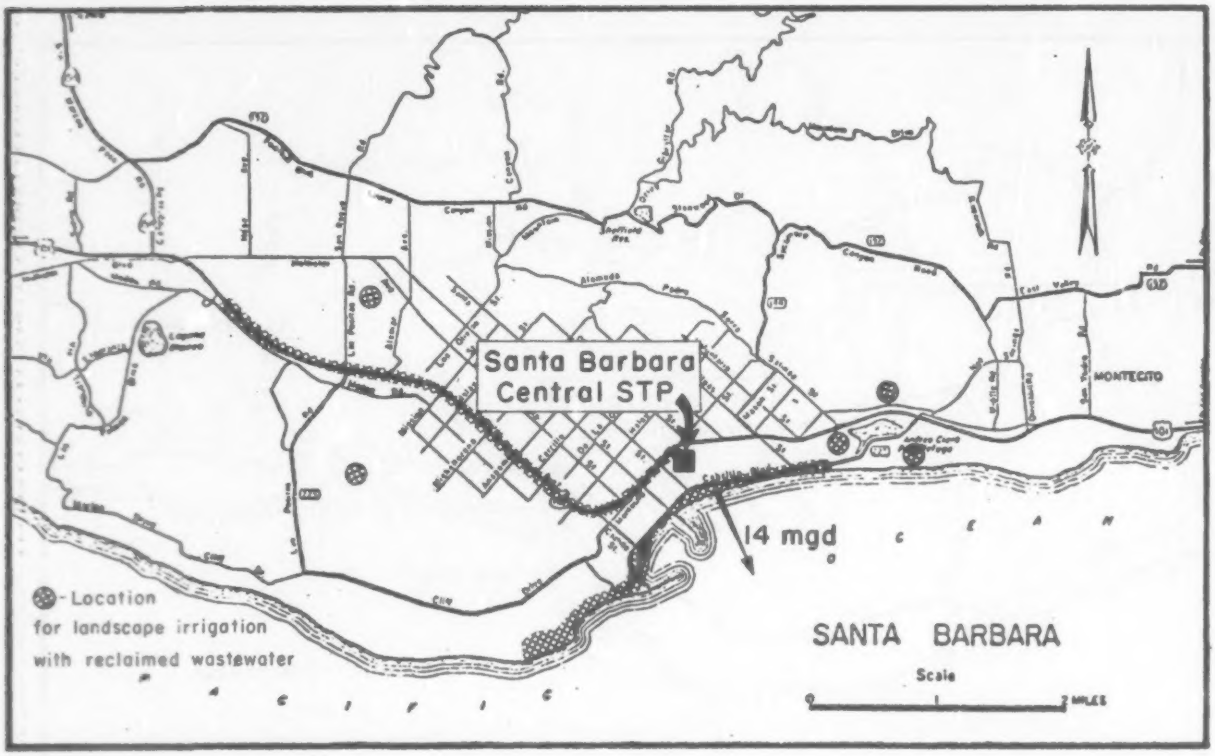

Santa Barbara
Central STP
14 mgd
MONTECITO
⊗ - Location
for landscape irrigation
with reclaimed wastewater
SANTA BARBARA
Scale
0
1
2 MILES
P A C I F I C
O C E A N

FIGURE VI-5

ALTERNATIVE 2
WASTEWATER TREATMENT AND EFFLUENT ROUTING

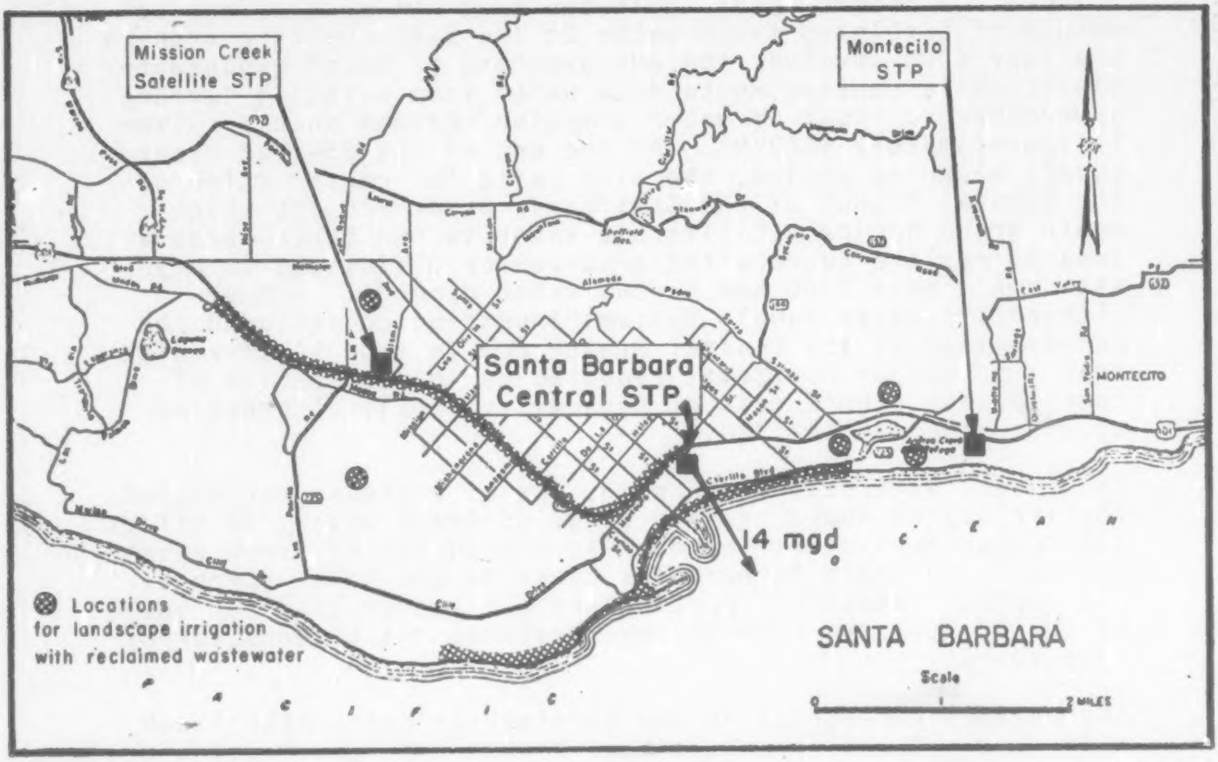

Mission Creek Satellite STP
Montecito STP
Santa Barbara Central STP
14 mgd
MONTECITO
O C E A N
Locations for landscape irrigation with reclaimed wastewater
P A C I F I C
SANTA BARBARA
Scale
0
1
2 MILES

FIGURE VI-6

ALTERNATIVE 3
WASTEWATER TREATMENT AND EFFLUENT ROUTING

is legal in California and is widely practiced. However, the city of Santa Barbara lacks sufficient area for such groundwater recharge practice.)

The three alternative wastewater treatment and effluent routing systems must also be viewed in the context of Santa Barbara's water supply situation. Under Alternative 1, which incorporates no wastewater reclamation, Santa Barbara must provide the full volume of water demand from fresh water sources. A recent study indicates that the cost-effective method of supplying fresh water to the Santa Barbara area to the year 2000 involves the overdrafting of local groundwater basins while continuing to draw water from existing surface impoundments. Cost of water supplied through such a system is approximately $583/MG. At the end of the 25-year water supply planning period, the plan calls for construction of the Coastal Branch of the California Water Project which would bring Northern California water to the Santa Barbara area to replace overdrafted groundwater basins and supply the area's year 2000 and beyond water demands. (Other alternative water supply systems investigated included the construction of the Coastal Branch now to import water with some groundwater overdraft required during the period of construction. Unit cost of such water supply alternative is approximately $921/MG.)

Under both Alternatives 2 and 3, use of wastewater effluent for irrigation would replace 2 mgd of fresh water, in effect causing an equivalent increase in the supply of fresh water available to Santa Barbara for domestic and other purposes. The overall impact of implementing a reuse program now would be to postpone the need for overdrafting the groundwater by five years.

The capital and operating and maintenance costs associated with each alternative wastewater processing system and the water supply system have been determined from existing information, including previous reports and estimating handbooks. These costs are shown on Tables VI-9 and VI-10, respectively.

Calculations using these basic costs indicate that the present value of each wastewater processing and water supply alternative are as follows:

Alternative 1 - $21,075,000

Alternative 2 - $20,129,000

Alternative 3 - $21,947,000

TABLE VI-9

COSTS FOR ALTERNATIVE WASTEWATER PROCESSING SYSTEMS[2] (1974 dollars)[a]

Item	Capital Cost	Operating and Maintenance Cost
16 mgd Advanced Biological Treatment Plant, adjacent to present SBWTF site	$7,725,000	$654,000
12 mgd Advanced Biological Treatment Plant, adjacent to present SBWTF site	$6,126,000	$552,000
2.6 mgd Advanced Biological Treatment Plant at Mission Creek	$1,550,000	$192,000
1.4 mgd expansion of Montecito Wastewater Treatment Facility	$ 686,000	$128,000
Delivery system for landscape irrigation, Central SBWTF	$2,122,000	$ 19,000
Central SBWTF plus satellite plants	$1,053,000	$ 10,000

[a] Original cost estimates have been multiplied by 1.28 to reflect the change in the ENR Construction Cost Index between 1971 and June 1974.

TABLE VI-10

COSTS FOR THE ONE COST-EFFECTIVE WATER SUPPLY SYSTEM IDENTIFIED FOR SANTA BARBARA[1a]

	1975	1980	1985	1990
Capital Cost[a]	424	636	530	530
Operating Cost[b]				
Overdraft[a]	31	93	235	378
Replacement Supply[a]	374	374	374	374
State Obligation	62	62	62	62
Total	467	529	671	814

[a] Costs in thousands of dollars.
Original cost estimates have been multiplied by 1.06 to reflect the change in the ENR Construction Cost Index between 1973 and June 1974.

[b] Original operating cost estimates were multipled by 0.31 to reflect the approximate share of the cost for Santa Barbara County borne by the city of Santa Barbara.

It is apparent that Alternative 2 is the cost-effective system and should be implemented if cost alone were the determining selection criteria.

The method used in calculating these present value figures for each alternative are shown on Tables VI-11, VI-12, and VI-13, for Alternatives 1, 2, and 3, respectively. EPA cost-effectiveness guidelines as shown on Table V-2 are followed throughout, including the use of a 7 percent interest rate and a 20-year planning period.

TABLE VI-11

CALCULATION OF PRESENT VALUE COSTS
SANTA BARBARA CASE STUDY
ALTERNATIVE 1

Overdrafting ground basin, 16 mgd secondary treatment plant adjacent to the present central sewage plant but no wastewater reuse.

	Capital	Single Payment Factor	Present Value of Capital	Annual O&M Cost	Uniform Series Factor	Single Payment Factor	Present Value of O&M Cost
1975 A[a]	424	1.000	424	467	4.100	1.000	1,915
B	7,732	1.000	7,732	654	4.100	1.000	2,681
1980 A	636	0.713	453	529	4.100	0.713	1,546
B				654	4.100	0.713	1,912
1985 A	530	0.508	269	671	4.100	0.508	1,398
B				654	4.100	0.508	1,362
1990 A	530	0.362	192	814	4.100	0.362	1,208
B				654	4.100	0.362	971
Total			9,070				12,993

---

[a] The designation A refers to costs associated with waste supply systems. The designation B refers to wastewater treatment and effluent routing costs.

TABLE VI-11 Continued

	Salvage Value of Equipment & Structures	Single Payment Factor	Present Value of Salvage	Present Value of Total Cost
1975 A	141	0.258	36	
B	2,577	0.258	665	
1980 A	318	0.258	82	
B				
1985 A	353	0.258	91	
B				
1990 A	442	0.258	114	
B				
Total			998	21,073

TABLE VI-12

CALCULATION OF PRESENT VALUE COSTS
SANTA BARBARA CASE STUDY
ALTERNATIVE 2

16 mgd secondary treatment plant adjacent to the present central sewage plant with wastewater reuse, no overdrafting of groundwater basin until 1980.

		Capital	Single payment factor	Present value of capital	Annual O&M costs	Uniform series factor	Single payment factor	Present value of O&M cost
1975	A	-	-	-	-	-	-	-
	B	9,847	1.000	9,847	673	4.100	1.000	2,759
1980	A	424	0.713	302	467	4.100	0.713	1,365
	B	-	-	-	673	4.100	0.713	1,967
1985	A	636	0.508	323	529	4.100	0.508	1,102
	B	-	-	-	673	4.100	0.508	1,402
1990	A	530	0.362	192	671	4.100	0.362	996
	B	-	-	-	673	4.100	0.362	999
Total				10,664				10,590

TABLE VI-12 (Continued) ALTERNATIVE 2

		Salvage value of equipment and structures	Single payment factor	Present value of salvage	Present value of total cost
1975	A	-	-	-	
	B	3,282	0.258	847	
1980	A	212	0.258	55	
	B	-	-	-	
1985	A	424	0.258	109	
	B	-	-	-	
1990	A	442	0.258	114	
	B	-	-	-	
Total				1,125	20,129

TABLE VI-13

CALCULATION OF PRESENT VALUE COSTS
SANTA BARBARA CASE STUDY
ALTERNATIVE 3

12 mgd secondary treatment plant adjacent to the present central sewage plant, a 2.6 advanced biological satellite plant at Mission Creek, expansion of the Montecito plant, wastewater reuse, and no overdrafting of the groundwater basin.

		Capital	Single payment factor	Present value of capital	Annual O&M costs	Uniform series factor	Single payment factor	Present value of O&M cost
1975	A	-	-	-	-	-	-	-
	B	9,415	1.000	9,415	882	4.100	1.000	3,616
1980	A	424	0.713	302	467	4.100	0.713	1,365
	B	-	-	-	882	4.100	0.713	2,578
1985	A	636	0.508	323	529	4.100	0.508	1,102
	B	-	-	-	882	4.100	0.508	1,837
1990	A	530	0.362	192	671	4.100	0.362	996
	B	-	-	-	882	4.100	0.362	1,309
Total				10,232				12,803

TABLE VI-13 (Continued) ALTERNATIVE 3

		Salvage value of equipment and structures	Single payment factor	Present value of salvage	Present value of total cost
1975	A	-	-	-	
	B	3,138	0.258	810	
1980	A	212	0.258	55	
	B	-	-	-	
1985	A	424	0.258	109	
	B	-	-	-	
1990	A	442	0.258	114	
	B	-	-	-	
Total				1,088	21,947

CHAPTER VI

REFERENCES

1. Toups Corporation. Water Resources Management Study, South Coast-Santa Barbara County. July 1974.

2. Engineering-Science, Inc. Regional Wastewater Management and Water Reclamation for Santa Barbara. August 1971.

CHAPTER VII

CASE STUDY - HAMPTON ROADS SANITATION DISTRICT

The northern half of the Hampton Roads Sanitation District (HRSD) is located on the peninsula of the Tidewater Region of Virginia (see Figure VII-1). The peninsula region is bordered by the York River, the Chesapeake Bay, the James River, and by New Kent (County) and Charles City.

At the present time, the HRSD is planning to construct a new sewage treatment plant at Goodwin Neck (see Figure VII-2). This facility is being constructed to relieve the loads presently imposed upon two existing treatment facilities.

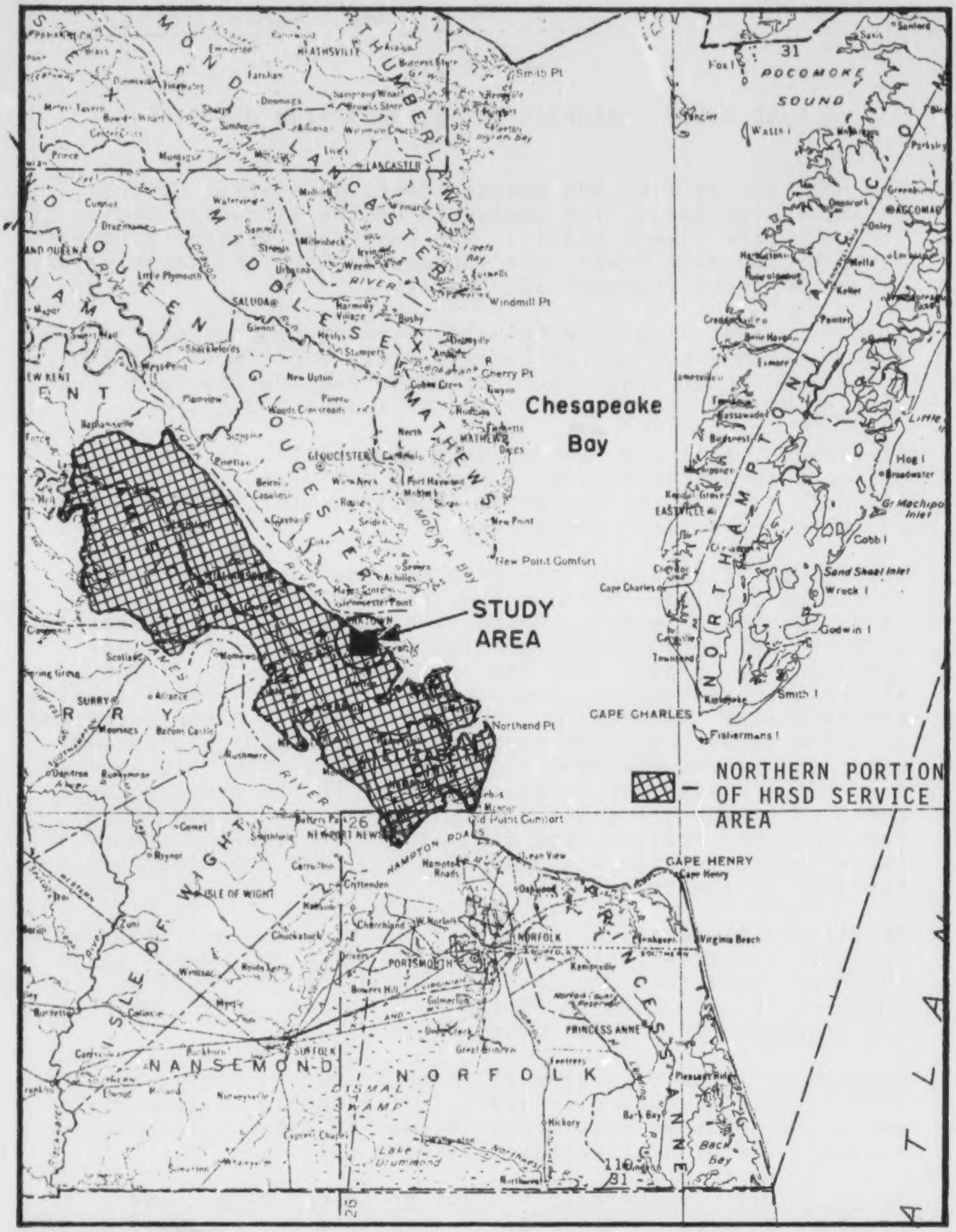
As planned, this new Goodwin Neck plant will discharge its effluent to the York River. However, HRSD is also considering the sale of effluent to nearby industries to offset a portion of the new treatment plant costs.

Located relatively near the proposed Goodwin Neck sewage treatment plant are various industrial plants, which use large volumes of water, including the American Oil Company's Yorktown Refinery (AMOCO) and the Virginia Electric Power Company power plant. For the purposes of this case study, alternative methods of supplying only the AMOCO facility with effluent were investigated, primarily because AMOCO expressed a desire to decrease its dependency on the region's potable water supply and agreed to cooperate fully with this study. The AMOCO refinery is located adjacent to the proposed Goodwin Neck sewage treatment plant, as shown on Figure VII-2. Pertinent information regarding other potential customers of reclaimed wastewater was unavailable within the time constraints of the study.

Results of the analyses conducted during this case study show that it is cost-effective to reclaim about 6.0 mgd of wastewater effluent from the Goodwin Neck plant for reuse at the AMOCO refinery. Details of the cost-effectiveness analysis are presented in the following sections.

Background. Basic background information concerning the area's physical characteristics, water supply system, and wastewater disposal network is necessary for a cost-effectiveness analysis of wastewater reuse options.

Geographical, Geological, and Topographical Data. The northern portion of the HRSD is comprised of the counties of James City and York, the town of Poquoson, and the cities of Hampton, Newport News, and Williamsburg. The HRSD lies within


Chesapeake Bay
STUDY AREA
NORTHERN PORTION OF HRSD SERVICE AREA
POCOMOKE SOUND
CAPE CHARLES
CAPE HENRY
HAMPTON ROADS
NORFOLK
PORTSMOUTH
NEWPORT NEWS
NANSEMOND
ISLE OF WIGHT
GLOUCESTER
MATHEWS
MIDDLESEX
LANCASTER
NORTHUMBERLAND
NORTHAMPTON
PRINCESS ANNE
DISMAL SWAMP
Lake Drummond
New Point Comfort
Northend Pt
Old Point Comfort
Windmill Pt
Smith Pt
Cherry Pt

Reproduced from best available copy.

FIGURE VII-1

HAMPTON ROADS SANITATION DISTRICT
LOCATION MAP

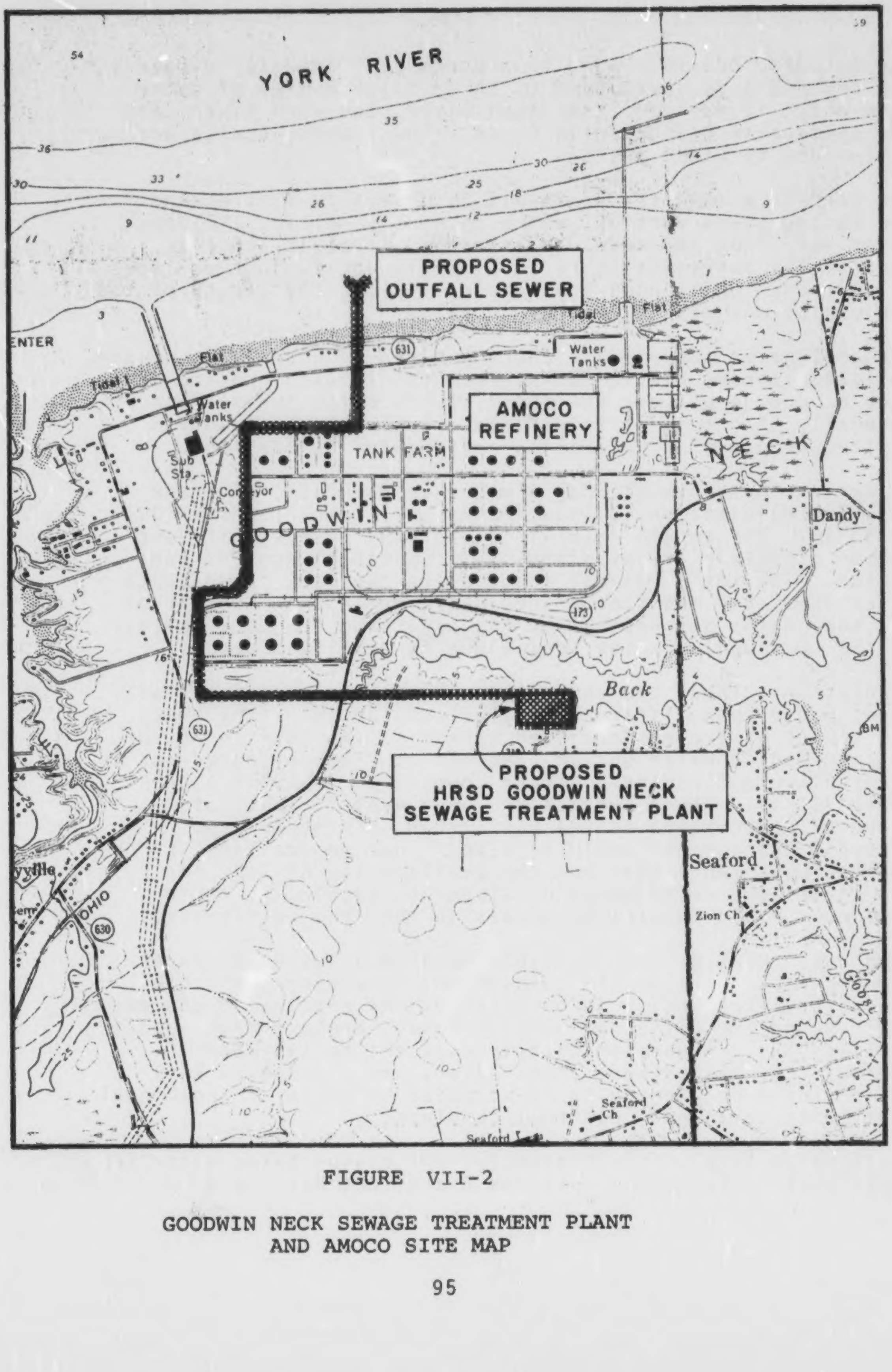

YORK RIVER
PROPOSED OUTFALL SEWER
AMOCO REFINERY
TANK FARM
Water Tanks
Sub Sta
Conveyor
GOODWIN
NECK
Dandy
Back
PROPOSED HRSD GOODWIN NECK SEWAGE TREATMENT PLANT
Seaford
Zion Ch
Seaford Ch
Tidal Flat
631
173
630
OHIO

FIGURE VII-2

GOODWIN NECK SEWAGE TREATMENT PLANT AND AMOCO SITE MAP the Atlantic Coastal Plain area known as "Tidewater Virginia." The peninsula is surrounded by three major bodies of water into which it drains: the James River, the York River, and the Chesapeake Bay/Atlantic Ocean. These water bodies are saline due to tidal action.

The terrain within the peninsula is generally flat except for the northwestern portion, which is gently rolling. Elevations vary from sea level to a maximum of about 125 feet. Most of the peninsula is at an elevation of 40 feet or less. A low ridge, which runs southeasterly along the length of the peninsula, divides it roughly in half.

The geology of the area is characterized by underlying unconsolidated sands, clays, marls, and gravels with granite base rock occurring between 800 and 2,000 ft below the surface. Generally, the soil is relatively impermeable, and only a limited amount of high quality groundwater is available.

Climate. The peninsula has a moderate rainfall. Average annual precipitation is about 45 in., with low years of 30 to 35 in. The annual rainfall is not the most significant factor affecting the availability of potable water in the region. The most critical factors are the lack of adequate water shed area and storage capacity, which are a result of the topography and geology of the area, and the poor quality of the surrounding water bodies due to tidal influences.

Population. There are various population projections available, based upon different assumptions for the study area. The source of projections used herein is the Interim Metropolitan Region Water Quality Management Plan, prepared for the Peninsula Planning District Commission in 1971[2] (see Table VII-1). These projections were used for case study purposes. According to EPA Guidelines, the most recent Series E projections would be used.[1] Due to availability of recreational facilities and the availability of land for industrial and residential developments within the region, continued rapid population growth in the area is expected.

Land Use. Much of the available land is occupied by farms and other open space; the bulk of the remaining available land within the region is occupied by the population concentrations of the cities of Hampton Roads, Newport News, and Williamsburg. Areas immediately adjacent to the water courses (the York River, James River, and Chesapeake Bay) are occupied or planned to be occupied by either recreational facilities or large industrial complexes.

Fresh Water Supply.[2,3] Presently, the region takes water from three small reservoirs: Skiffes Creek, Lee Hall, and

TABLE VII-1[1]

SERVICE AREA POPULATION DATA

	Past		
	1950	1960	1970
Hampton	60,994	89,258	120,779
Newport News	82,233	113,662	138,177
Williamsburg	6,735	6,832	9,069
James City County	6,317	11,539	17,853
York County	11,750	17,305	27,762
Poquoson	a	4,278	5,441
	168,029	242,874	319,081

	Future		
	1980	1990	2000
Hampton	152,000	179,000	207,100
Newport News	168,900	196,900	218,300
Williamsburg	11,700	14,300	16,900
James City County	31,100	44,200	56,900
York County	49,800	71,800	94,100
Poquoson	10,600	14,800	19,000
	424,100	521,000	612,300

[a] Included in York County population.

Harwoods Mill, and from a new dam on the Chickahominy River. The resulting maximum safe yield of the combined system is 35 mgd.

Other capital improvements, such as the installation of additional pumping capacity to Walkers Dam (already completed) and the planned construction of 6 billion gallon reservoir on Little Creek will add an additional maximum safe yield of 25 mgd. Thus the total safe yield will be 60 mgd.

Fresh Water Demands and Cost. Overall demand for water in the HRSD case study area is expected to be about 60.5 mgd by the year 2000, based on estimated population increases, as illustrated on Figure VII-3. Since the safe yield of the water supply system will be approximately 60 mgd, a small potential shortage situation is projected.

The capital expenditures required to construct such planned facilities as the Little Creek reservoir to supply the potable water demand of the peninsula region will increase water rates. In anticipation of these new capital improvements, a water rate study was prepared for the Newport News Water Works in 1971.[4]

Knowledge of the actual marginal costs of constructing new water supply facilities is, of course, necessary for local planners and decision-makers. For the purposes of a wastewater reuse cost-effectiveness analysis, however, it is the sales price of water to customers that is the most important consideration. As the Newport News Water Works rate study recommended, a rate increase of about 25 percent was instituted in July, 1971. This rate was to have been in effect through June, 1976. However, as a result of increases in the costs of labor, material, electricity, and general inflation, an additional rate increase was instituted in mid-1974. At that time, rates for major users increased from $0.21 to $0.26 per 100 cu ft. Further analysis indicated another increase to $0.30 per 100 cu ft will be required prior to March, 1975. Estimates indicate that water rates can be expected to increase further to $0.35 per 100 cu ft within the foreseeable future.

Sewage Facilities. Presently, most of the municipal wastewater generated within the District is discharged into the James River from three existing HRSD plants: Boat Harbor James River, and Williamsburg. The Boat Harbor plant provides primary treatment, and the James River and Williamsburg plants provide secondary treatment. These facilities will soon be overloaded due to growth of the peninsula area. The Boat Harbor plant is scheduled for expansion and upgrading to secondary treatment standards. To accommodate this

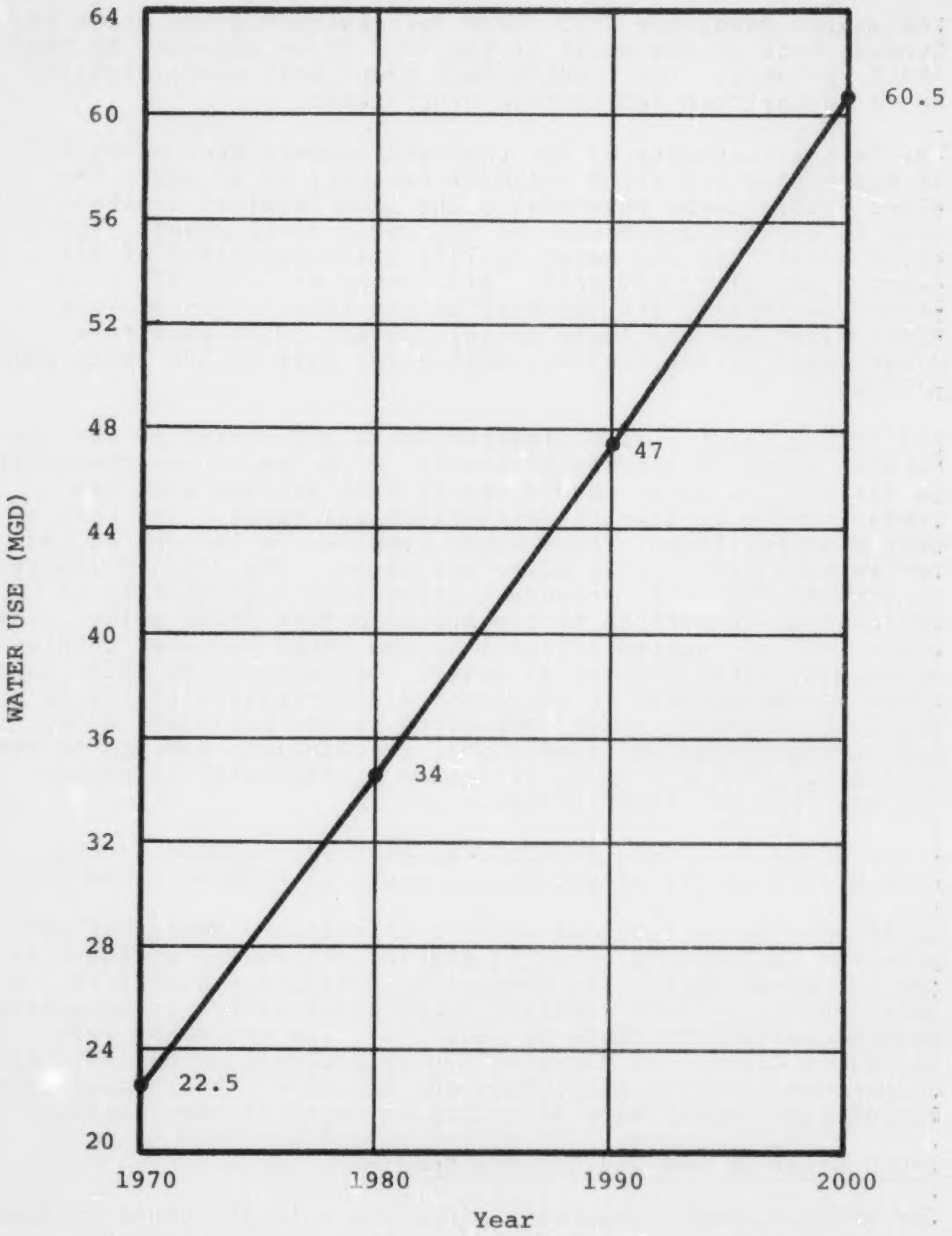


FIGURE VII-3
PROJECTED WATER USE IN HRSD CASE STUDY AREA

additional load, the HRSD plans to construct a new plant at Goodwin Neck at the mouth of the York River adjacent to the AMOCO refinery. The Goodwin Neck plant will serve District No. 2 in Yorktown and certain other areas.

The initial capacity of the proposed Goodwin Neck plant is 15 mgd with a projected ultimate capacity of 30 mgd. The plant will provide essentially the same level of treatment that is presently provided at the James River plant. Table VII-2 summarizes the water quality characteristics of the James River plant effluent. Also shown on Table VII-2 for later comparisons are the quality characteristics of York River water and available potable water. Note that York River water is very saline, with a TDS over 20,000 parts per million.

Preliminary Test: Is Wastewater Reuse a Possibility for the Hampton Roads Sanitation District? A review of the checklist in Table VII-3 shows conditions in HRSD service area are conducive for wastewater reclamation and reuse. The cost of providing additional fresh water supplies is increasing, as reflected in the rising water use rates. The planned sewage treatment plant will produce a relatively high quality of effluent in comparison to the brackish York River water. The plant will be located adjacent to the AMOCO refinery complex which uses large volumes of water. Consultants to HRSD consider it impractical to construct a distribution system to supply effluent to other industries in the peninsula area. Due to the geological conditions, groundwater recharge is not possible; and there is no irrigated agricultural or recreational land in the vicinity.

Given these favorable conditions, an investigation of the cost-effectiveness of wastewater reuse at HRSD is warranted.

In the following sections we will discuss the technical and economic feasibility of using treated wastewater effluent at the AMOCO refinery. The discussion provides a guideline for local agency-private industry cooperative effort to ascertain whether wastewater reuse is feasible. The procedure presented is typical of the preliminary analysis which would be undertaken by any municipality and industry, though obviously actual costs would vary depending on local circumstances.

AMOCO Water Volume and Quality Needs

The AMOCO refinery presently withdraws a total volume of about 81 mgd in the summer and 51 mgd in the winter. Over 95 percent of this volume is taken from the highly saline York River for use in the once-through cooling system. Water for other uses is purchased potable water. Seasonal variations

TABLE VII-2

WATER QUALITY CHARACTERISTICS OF AVAILABLE POTABLE WATER, THE YORK RIVER, AND THE HRSD'S JAMES RIVER SEWAGE TREATMENT PLANT EFFLUENT

Parameter	Potable water		York River cooling water	Effluent quality expected from Goodwin Neck Plant[a]	
	Avg.	Range		Avg.	Range
Ca [b]	72	58-92			
Mg	3.7	2.0-6.0			
Na					
Cu				.076	.060-.08
Zn				.11	.06-.15
Pb				.100	.100
Cr				.007	.007
Al	.1	.1			
Fe	.1	.1-.16			
SiO_2	5.2	2.1-7.5			
HCO_3	78	47 -110			
Total hardness	83	61-94		95	83 -104
Cl	19	17-24			
Florides	.94	.25-1.0			
Sulfate	40	33 -47			
P			.06		
Phosphate				6.4	3.8 -8.2
Nitrate			.05		
Ammonia			b	16	10-25
TKN				18	25-30
P-Alkalinity	0	0			
M-Alkalinity	40	24-60	80		

TABLE VII-2 (Continued)

Parameter	Potable water		York River cooling water	Effluent quality expected from Goodwin Neck Plant[a]	
	Avg.	Range		Avg.	Range
pH	7.2	7.0-7.3	7.5	7.0	6.9-7.0
TDS	130	111 -148	20457	422	344 -468
TSS			36	32	8-72
TVS	47	32-61	3420	119	89-183
TS			20493		
Residual Min.	83	79-91			
Oil and Grease			3		
BOD			1.3	15	10-24
COD			49		
TOC			14		
CO_2	5.3	2-9			
Soap Hardness	75	60-94			
CO_3					
Consumption/output MGD	1.25[c] 1.375[d]		50[d]-80[c]	15[e] 30[f]	

[a] Same as the existing effluent from the James River Stp.

[b] All parameters expressed as ppm of $CaCO_3$.

[c] Present summer consumption.

[d] Present winter consumption.

[e] First phase capacity of Goodwin Neck.

[f] Projected ultimate capacity of Goodwin Neck.

TABLE VII-3

CHECKLIST FOR DETERMINING IF WASTEWATER REUSE IS POTENTIALLY PRACTICAL FOR HRSD AREA

Wastewater reuse is potentially practical if one or more of the following factors are true for your area. A more complete economic analysis should then be performed.

☑ 1. Existing or future fresh water supply is limited.

☑ 2. Existing or future fresh water supply is relatively expensive.

☑ 3. The area presently includes or will include individual entities who use high volumes of water.

☑ 4. Municipal wastewater of relatively high quality is presently discharged for disposal or soon will be.

☑ 5. Requirements for improved wastewater effluent are impending or are anticipated.

☐ 6. Wastewater disposal is expensive, e.g., a long outfall line is required.

---

in volume required by the refinery are due to lower winter temperatures of the York River cooling water. Table VII-4 summarizes the major specific uses and present sources of water supply into the refinery.

Present water quality of the York River and the local potable water supply was shown in Table VII-2. In terms of inorganic constituents, the potable supply is good quality, and the York River is poor quality, virtually seawater--satisfactory, however, for a once-through cooling system.

As a result of forthcoming EPA effluent limitations, the refinery may be required to install cooling towers in order to stop the discharge of warm water into the York River. The cost of once-through cooling towers for the summer flow of 81 mgd is prohibitive. In addition, the use of saline water in cooling towers may create additional environmental problems such as salt water drift, a condition where the cooling tower exhaust plume contains substantial salt which is deposited over a wide area surrounding the cooling tower.

The cooling system would then be a recirculating system and require an estimated daily volume of 6 mgd of cooling tower make-up water, as compared to the present volume of 51 to 81 mgd.

Typical quality requirements for cooling tower make-up water are shown in Table VII-5. The York River water presently used for cooling is too high in TDS, sulphates, etc. to use as cooling tower make-up water in a recirculating system; therefore, the refinery will be left with a choice between their potable water supply and reclaimed wastewater from HRSD as a source of 6 mgd of future cooling tower make-up water. In addition, if it is economically feasible to use reclaimed wastewater for cooling tower make-up water, then a further analysis is desirable to determine if reclaimed effluent should also be used for boiler feedwater make-up. Volume requirements for boiler feedwater make-up at AMOCO are shown in Table VII-4 as 0.55 mgd, and typical quality requirements are shown in Table VII-6.

Additional Treatment Required for Reclaimed Effluent

In comparing costs of using reclaimed effleunt vs. using a potable supply for industrial purposes the engineer will normally find that, (1) the price of procuring the potable supply is more than the price of procuring the reclaimed effluent; however, (2) the reclaimed effluent requires more pumping, storage, and treatment facilities to make reclaimed effluent comparable to the potable water supply. The technical and cost data used for background in this discussion

TABLE VII-4

WATER USE AT THE YORKTOWN AMOCO REFINERY

Use	Source	Present volume used[a] (mgd)	Expected volume used[b] (mgd)
Processing and potable	Newport News Water Works	0.70	0.70
Boiler feed	Newport News Water Works	0.55	0.55
Cooling			
Summer	York River	80.00	6.0
Winter	York River	50.00	average
Total			
Summer		81.25	7.25
Winter		51.25	average

[a] Once-through cooling system in use.

[b] After installation of a recirculating cooling system.

TABLE VII-5

REPORTED COOLING WATER QUALITY FOR MAKE-UP WATER TO RECIRCULATING SYSTEMS

Parameter	Range in reported values	Comment
Cl	100-500	
TDS	500-1,650	
Hardness (CaCO$_3$)	50-130	
Alkalinity (CaCO$_3$)	20-	
pH	6.9-9.0	preferably 6.8-7.2
COD	75-	preferably below 10
TSS	25-100	preferably below 10
Turbidity	50-	preferably below 10
BOD	25-	preferably below 5
MBAS	2-	2 is good
NH$_3$	4-	preferably below 1
PO$_4$	1-	1 is good
Al	0.1	
Fe	0.5	
Mn	0.5	
Ca	50	
Mg	0.5 aar[a]	
HCO$_3$	24	
SO$_4$	200	

[a] aar - accepted as received.

TABLE VII-6

QUALITY OF WATER USED FOR BOILER FEED AT THE AMOCO REFINERY

Parameter	Concentration (ppm as $CaCO_3$)
Ca	0.1
Mg	0.1
HCO_3	2.6
Total hardness	0.2
Sulfate	46.0
P-Alkalinity	0.2
M-Alkalinity	3.0
TDS	130
CO_3	0.4
Cl	20.0

is mainly derived from experience at other locations which are using reclaimed municipal effluent for cooling tower and/or boiler feedwater make-up. In addition, equipment manufacturers were interviewed to obtain current (1974) prices and verify technical criteria.

Figure VII-4 shows the basic treatment chain being used successfully at six out of eight existing operations where municipal effluent is being further treated for use as cooling tower make-up water. The basic system entails a storage pond; lime clarification for removal of suspended solids, phosphates, silicates and organics; and high dosages of corrosion inhibitor, algaecides and bacteriacides.

Figure VII-5 shows the basic treatment chain being used successfully at the three existing operations where municipal effluent is being further treated for use as boiler feedwater make-up. The treatment chain basically adds filtration and softening steps to follow the lime clarification described in the previous paragraph to treat the water for cooling tower make-up.

In this case study the effluent outfall line from the HRSD treatment plant passes through the AMOCO refinery, so there is no additional cost involved for transporting the effluent to the industrial user. (In some other locations, transportation of the effluent may be a major cost factor.) There will be, however, a small cost for pumping the reclaimed effluent from the storage pond, which is not necessary if the potable supply were used because the potable supply is already pressurized.

Cost Analysis for Use of Reclaimed Effluent vs. Potable Water Source

In this subsection is presented a narrative discussion and tables illustrating a simplified cost analysis of three water source alternates for the AMOCO refinery. These are:

1. Use now (1975) of existing potable water supply for both cooling water make-up and boiler feedwater make-up.

2. Use now (1975) of reclaimed HRSD effluent for both cooling water make-up and boiler feedwater make-up.

3. Use now (1975) of reclaimed HRSD effluent for cooling water make-up and existing potable water supply for boiler feedwater make-up.

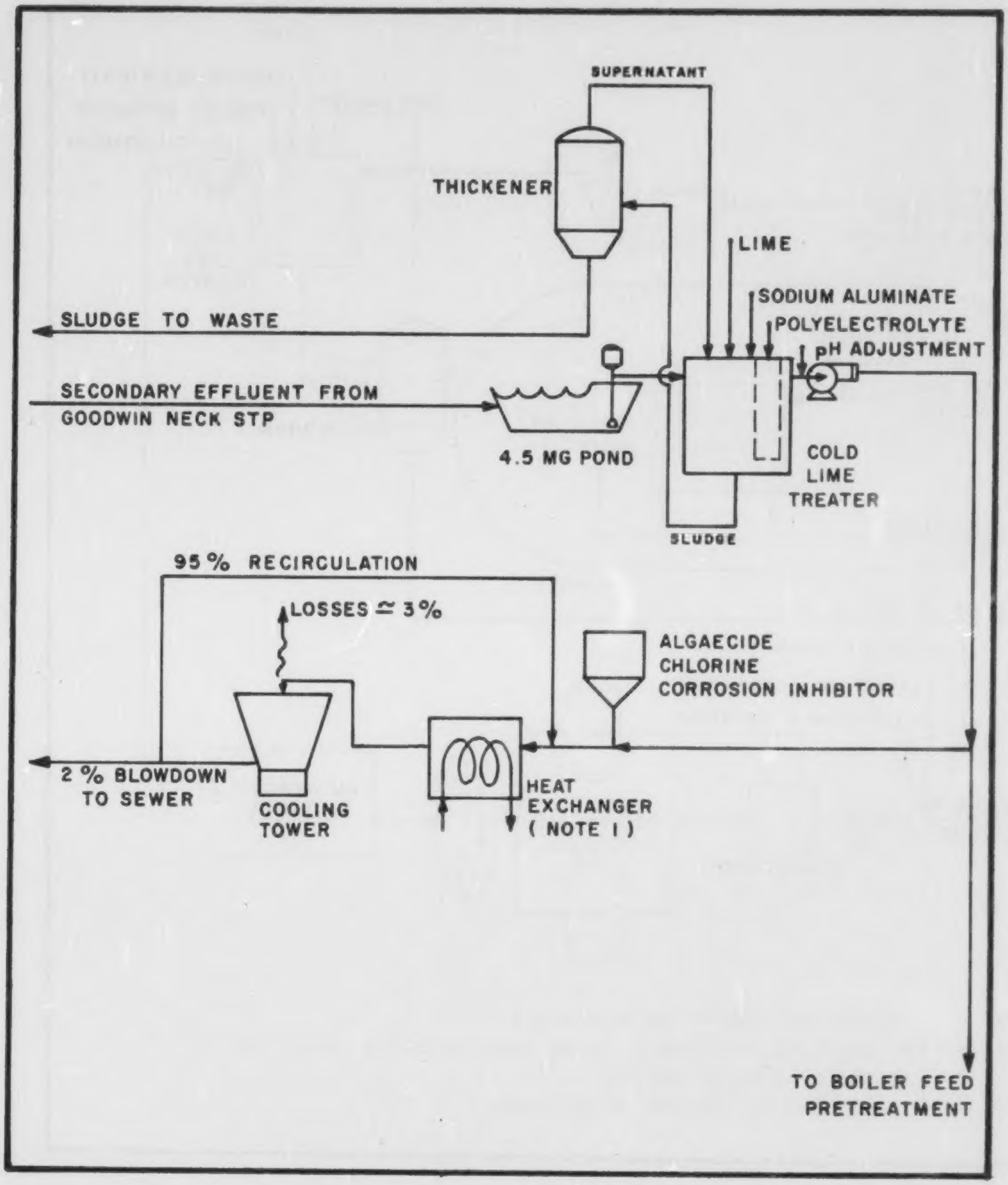
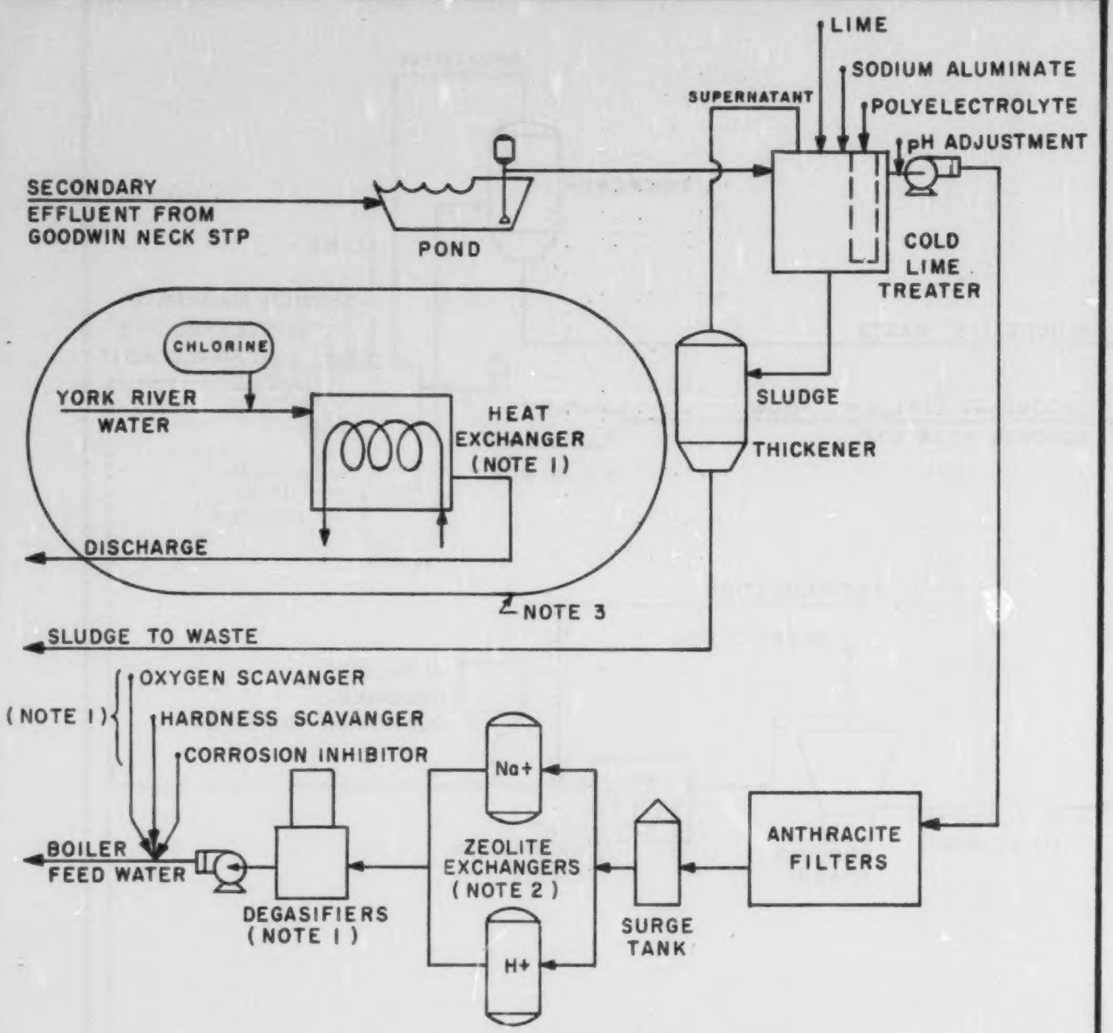

SUPERNATANT
THICKENER
LIME
SODIUM ALUMINATE
POLYELECTROLYTE
pH ADJUSTMENT
SLUDGE TO WASTE
SECONDARY EFFLUENT FROM
GOODWIN NECK STP
4.5 MG POND
COLD
LIME
TREATER
SLUDGE
95% RECIRCULATION
LOSSES ≃ 3%
ALGAECIDE
CHLORINE
CORROSION INHIBITOR
2% BLOWDOWN
TO SEWER
COOLING
TOWER
HEAT
EXCHANGER
(NOTE I)
TO BOILER FEED
PRETREATMENT

FIGURE VII-4

IN-PLANT PROCESSING FOR UPGRADING SECONDARY EFFLUENT FOR COOLING TOWER MAKE-UP WATER


LIME
SODIUM ALUMINATE
SUPERNATANT
POLYELECTROLYTE
pH ADJUSTMENT
SECONDARY EFFLUENT FROM GOODWIN NECK STP
POND
COLD LIME TREATER
CHLORINE
YORK RIVER WATER
HEAT EXCHANGER (NOTE 1)
SLUDGE
THICKENER
DISCHARGE
NOTE 3
SLUDGE TO WASTE
OXYGEN SCAVANGER
(NOTE 1)
HARDNESS SCAVANGER
CORROSION INHIBITOR
Na+
ZEOLITE EXCHANGERS (NOTE 2)
H+
BOILER FEED WATER
DEGASIFIERS (NOTE 1)
SURGE TANK
ANTHRACITE FILTERS

NOTE 1. EXISTING EQUIPMENT OR ADDITIVES.

NOTE 2. TWO EXISTING SOFTENERS TO BE SUPPLEMENTED WITH TWO ADDITIONAL ZEOLITE UNITS.

NOTE 3. COOLING SYSTEM SHOWN IS EXISTING.

FIGURE VII-5

IN-PLANT PROCESSING FOR UPGRADING SECONDARY EFFLUENT FOR BOILER FEEDWATER

Capital and annual operation and maintenance costs are estimated for each alternate based on costs experienced for similar operations elsewhere and on current (1974) equipment, chemical and energy costs.

Table VII-7 shows that estimated operation and maintenance cost of using effluent for cooling tower make-up is $0.42/1,000 gal which is $0.13/1,000 gal less than the equivalent cost of using the potable water supply. This difference, however, does not include amortization of capital facilities required to store, pump and treat the reclaimed effluent. The capital cost of these required facilities is estimated at $340,000, as shown in Table VII-8. The question of economic feasibility thus hinges upon the cost per 1,000 gal of amortizing the capital expenditure for storage, pumping and treatment facilities. In an equipment life of 20 years, an interst rate of 10 percent, and no salvage value is assumed then the cost of amortizing capital is only 1.8c/1,000 gal as calculated below:

Estimated capital cost = $340,000
crf at 10% for 20 yr = 0.11746
annual amortization cost = 340,000 x 0.11746 = $39,936
annual volume = 6 mgd x 365 days = 2190 MG
cost per MG = $18.24 = 1.8c/1,000 gal

Based upon the above analysis there would be clear savings to AMOCO of 11.2c/1,000 gal if reclaimed effleunt is used instead of potable water for the cooling tower make-up water supply. This assumes that the HRSD gives away its effluent to AMOCO, i.e., AMOCO does not attempt to profit from sale of effluent. This cost of effluent is negotiable, of course, between the supplier and user.

As shown in Table VII-9, however, the use of reclaimed effluent for boiler feedwater would not be advantageous because the added treatment for reclaimed water, as shown in Figure VII-5, raises the O&M cost of the reclaimed use to 57c/1,000 gal which is 3c/1,000 gal higher than potable water.

TABLE VII-7

ESTIMATED O & M COST TO AMOCO FOR TREATMENT OF COOLING TOWER MAKE-UP

(Based upon 6 mgd average use)

Item	Potable water source c/1,000 gal	Reclaimed effluent source c/1,000 gal
Water cost	40[a]	0[b]
Chemicals		
Lime	0	4
Coagulant	0	2
Biocide	1	2
Inhibitors	2	4
pH control	2	5
Pumping	0	4
O&M	10	21
Total	55	42

[a] Equivalent to 30¢/100 cu ft

[b] Negotiable up to about 11¢ between supplier and user

TABLE VII-8

ESTIMATED CAPITAL COST TO AMOCO FOR TREATMENT FACILITIES FOR COOLING TOWER MAKE-UP

(Based on 6 mgd average use)

Item	Estimated cost $1,000
Storage pond	40
Pumping facility	30
Lime clarifier	150
Sludge treatment and disposal	60
Miscellaneous and contingencies	60
Additive metering	Same as for potable water
Instrumentation	Same as for potable water
All other facilities required	Same as for potable water
Total difference in capital facility cost to utilize reclaimed effluent	340

TABLE VII-9

ESTIMATED O&M COST TO AMOCO FOR TREATMENT OF BOILER FEED MAKE-UP

(Based upon 0.5 mgd average use)

Item	Potable water source c/1,000 gal	Reclaimed effluent source c/1,000 gal
Water cost	40	0
Chemicals		
Lime	0	4
Coagulant	0	2
Filter media	0	1
Brine	0	3
Acid	0	12
Inhibitors	2	4
Pumping	2	6
O&M	10	25
Total	54	57

CHAPTER VII

REFERENCES

1. Guidance for Facilities Planning (2nd ed.). Environmental Protection Agency, Washington, D.C., Oct. 1974.

2. Malcom Pirnie Engineers, Inc. Interim Metropolitan Regional Water Quality Management Plan. Peninsula Planning District Commission - Hampton, Virginia. Paramus, New Jersey, 1971.

3. Malcom Pirnie Engineers, Inc., and Coastal Zone Resources Corp. Environmental Assessment - Construction and Operations of a Water Storage Reservoir at Little Creek, James City County, Virginia. Newport News, Virginia, 1973.

4. Malcom Pirnie Engineers, Inc. Water Rate Study, Newport News Waterworks. Newport News, Virginia, 1971

BIBLIOGRAPHY

ECONOMICS

1. Adrien, Donald D., et al. A Methodology for Planning Optimal Regional Wastewater Management Systems. Amherst, University of Massachusetts, Water Resources Research Center, 1973.

2. Andrews, Richard A., and R. R. Weyrick. Values and Cost Allocations of Surface-Water Use and Treatment. New Hampshire Station Bulletin No. 500. Durham, New Hampshire Agricultural Experiment Station, Nov. 1972.

3. Arrow, K. J., and R. C. Lind. Uncertainty and the Evaluation of Public Investment Decisions. American Economic Review. p. 60, 1970.

4. Banks, H. O., et al. Economic and Industrial Analysis of Wastewater Reclamation and Reuse Projects. San Francisco, Leeds, Hill & Jewett, 1971.

5. Bargman, Robert D., W. Adrian, and D. C. Tillman. Planning, Testing, and Design for Water Reclamation for Los Angeles. Paper presented at ASCE National Meeting, Water Resources Engineering, 1973.

6. Berger, H. F. Evaluating Water Reclamation Against Rising Costs of Water and Effluent Treatment. Louisiana State University, Division of Engineering Research Bulletin. 89:155-168, 1967.

7. Bishop, A. B. An Approach to Evaluating Environmental, Social, and Economic Factors in Water Resources Planning. Water Resources Bulletin. (4):724-734, Aug. 1972.

8. Brams, Marvin R. A Case Study of the Application of Cost-Benefit Analysis to Water System Consolidation by Local Government. The Engineering Economist. 17(2), Jan.-Feb. 1972.

9. Cesario, F. J., and J. L. Knetsch. Time Bias in Recreation Benefit Estimates. Water Resources Research. 6(3):700-704, 1970.

10. Clark, Colin. The Economics of Irrigation. Oxford, Pergamon Press, 1967.

11. Clawson, M., and J. L. Knetsch. Economics of Outdoor Recreation. Baltimore, Johns Hopkins Press for Resources for the Future, 1966.

12. Cluff, C. B., K. J. DeCook, and W. G. Matlock. Technical, Economic, and Legal Aspects Involved in the Exchange of Sewage Effluent for Irrigation Water for Municipal Use--Case Study, City of Tucson. Tucson, University of Arizona, Dec. 1972.

13. Cluff, C. B., G. R. Dutt, P. R. Ogden, and J. K. Kuykendall. Development of Economic Water Harvesting Systems for Increasing Water Supply-Phase II. Project Completion Report, OWRR Project No. B-015-ARIZ. Tucson, University of Arizona, 1972.

14. Conley, Bryan C. Price Elasticity of the Demand for Water in Southern California. Annals of Regional Science. Western Washington State College, Economics Department. (Papers and proceedings of Western Section, Regional Science Association, Billingham, Washington. Dec. 1967). pp. 180-189.

15. Cootner, Paul H., and G. O. G. Lof. Water Demand for Steam Electric Generation, An Economic Projections Model. Baltimore, Johns Hopkins Press, Resources for the Future, 1965. pp. 34-35.

16. Cost Effectiveness in Water Quality Programs. U.S. Environmental Protection Agency, Washington, D.C., 1972.

17. Cost Effectiveness Studies of Sanitary Sewerage Systems - Methodology and Demonstration. U.S. Environmental Protection Agency, Washington, D.C., 1974.

18. Cost Estimating Guidelines for Wastewater Treatment Systems. U.S. Department of Interior, Washington, D.C., 1970.

19. Cost Factors for Water Supply and Effluents Disposal. Chemistry and Industry. pp. 667-683, 697-703, 1970.

20. Cuchetti, Charles J., _et al_. Benefits or Costs? An Assessment of the Water Resources Council's Proposed Principles and Standards. In: Benefit-Cost and Policy Analysis, Niskanen, W. A., ed., Chicago, Aldme Publishing Co., 1973.

21. Davis, R. K. Water Supply Economics in the Potomac River Basin. Journal of the American Water Works Association. 56:257, 1964.

22. Davis, R. K., and S. H. Hanke. Pricing and Efficiency in Water Resource Management. Benefit Cost Analysis, 1971. Chicago, Aldme Publishing Co., 1972.

23. DeCook, K. J. Economic Feasibility of Selective Adjustments in Use of Salvageable Waters in the Tucson Region, Arizona. Ph.D. Dissertation. Tucson, University of Arizona, 1970.

24. Douglas, James L., and R. R. Lee. Economics of Water Resources Planning. New York, McGraw-Hill Book Company, 1971.

25. Eckenfelder, W. W., Jr., and D. L. Ford. Economics of Wastewater Treatment. Chemical Engineering. p. 109, Aug. 1969.

26. Eckstein, Otto. A Survey of the Theory of Public Expenditure Criteria. Universities-National Bureau Committee for Economic Research. (In Public Finances: Needs, Sources, and Utilization.) Special Conference Series 12. Princeton, Princeton University Press, 1961.

27. Eckstein, Otto. Water Resource Development: The Economics of Project Evaluation. Cambridge, Harvard University Press, 1958.

28. Economic Analysis of Public Investment Decisions: Interest Rate Policy and Discounting Analysis. U.S. Congress, Joint Economic Committee, 90th Congress, 2nd Session, 1968.

29. Economics of Clean Water. U.S. Environmental Protection Agency, Washington, D.C., 1972.

30. The Economics of Water Supply and Quality, U.S. Environmental Protection Agency, Washington, D.C., 1971.

31. Eilers, Richard G., and R. Smith. Wastewater Treatment Plant Cost Estimating Program. Environmental Protection Agency, Washington, D.C., 1971.

32. English, J. Morley, ed. Cost Effectiveness--The Economic Evaluation of Engineered Systems. New York, John Wiley & Sons, Inc., 1968.

33. Erlich, Harry, and P. H. McGauher. Economic Evaluation of Water: Part II Jurisdictional Considerations in Water Resources Management. UC Berkeley, Sanitary Engineering Research Laboratory, June 1964.

34. Fair, G. M., and J. C. Geyer. Water Supply and Waste Water Disposal. New York, John Wiley and Sons, 1969.

35. Fourt, Louis. Forecasting the Urban Residential Demand for Water. Agricultural Economics Seminar paper. Chicago, Illinois, University of Chicago, Department of Economics, Feb. 1958.

36. Frankel, R. J. Water Quality Management: Engineering Economic Factors in Municipal Waste Disposal. Water Resources Research. 1(2):173-186, 1965.

37. Freeman, A. M., III. Six Federal Reclamation Projects and the Distribution of Income. Water Resources Research. 3(2):319-332, 1967.

38. Freeman, A. M., III, and R. H. Havemen. Benefit-Cost Analysis and Multiple Objectives: Current Issues in Water Resources Planning. Water Resources Research. 6(6):1533-1539, 1970.

39. Gardner, B. D., and S. H. Schick. Factors Affecting Consumption of Urban Household Water in Northern Utah. Agricultural Experiment Station Bulletin No. 449, Nov. 1964.

40. Gottlieb, Manual. Urban Domestic Demand for Water: A Kansas Case Study. Land Economics. pp. 204-210, May 1963.

41. Grant, Eugene L., and W. G. Ireson. Principles of Engineering Economy. New York, The Roland Press Company, 1960.

42. Grima, A. P. Lino. Residential Water Demand: Alternative Choices for Management. University of Toronto, Department of Geography, Research Publication No. 7. Toronto, University of Toronto Press, 1972.

43. Grubb, H. W., and J. T. Goodwin. Economic Evaluation of Water-Oriented Recreation in the Preliminary Texas Water Plan. Rep. 84, Texas Water Development Board, Austin, 1968.

44. Hanke, Steve H., and R. K. Davis. Demand Management Through Responsive Pricing. Journal of the American Water Works Association. pp. 555-560, Sept. 1971.

45. Hanke, S. H. Demand for Water Under Dynamic Conditions. Water Resources Research. 6(5):1253-1261, 1970.

46. Haveman, R. H. Ex-Post Analysis of Water Resource Projects. Baltimore, Johns Hopkins Press, 1971.

47. Haveman, R. H. The Opportunity Cost of Displaced Private Spending and the Social Discount Rate. Water Resources Research. 5(5):947-957, 1969.

48. Haveman, R. H. Water Resource Investment and the Public Interest. Nashville, Tenn., Vanderbilt University Press, 1965.

49. Haveman, R. H., and J. V. Krutilla. Unemployment, Idle Capacity, and the Evaluation of Public Expenditures: National and Regional Analyses. Baltimore, Johns Hopkins Press, 1968.

50. Headley, J. Charles. The Relation of Family Income and Use of Water for Residential and Commercial Purposes in the San Francisco-Oakland Metropolitan Area. Land Economics. pp. 441-449, 1963.

51. Hild, Joseph C. An Advanced Wastewater Treatment Plant Can Provide Revenue. Public Works. (7):49, July 1972.

52. Hinote, Hubert. Benefit-Cost Analysis for Water Resource Projects--A Selected Annotated Bibliography. Knoxville, University of Tennessee, June 1969.

53. Hirshleifer, J. C. DeHaven, and J. W. Milliman. Water Supply: Economics, Technology, and Policy. Chicago, The University of Chicago Press, 1960.

54. Hittman Associates, Inc. Price, Demand, Cost, and Revenue in Urban Water Utilities. U.S. Department of the Interior, Office of Water Resources Research. Contract No. 14-31-0001-3168. 1970.

55. Howe, Charles. Benefit-Cost Analysis for Water System Planning. American Geophysical Union, Water Resources Monograph 2. Washington, D.C., 1971.

56. Howe, C. W. Water Pricing in Residential Areas. Journal of the American Water Works Association. 60:(5), 1968.

57. Howe, C. W. Water Resources and Regional Economic Growth in the United States, 1950-1960. S. Econ. J. 34(4), 1968.

58. Howe, C. W., and K. W. Easter. Interbasin Transfers of Water: Economic Issues and Impacts. Baltimore, Johns Hopkins Press for Resources for the Future, 1971.

59. Howe, C. W., and F. P. Linaweaver, Jr. The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure. Water Resources Research, First Quarter. 3(1):13-32, 1967.

60. Hulschmidt, M., and M. Fiering. Simulation Techniques for Design of Water Resource Systems. Boston, Harvard University Press, 1966.

61. Institute of Water Resources. Development Benefits of Water Resources Investments. Department of the Army, Corps of Engineers, 1969.

62. James, Douglas, and R. R. Lee. Economics of Water Resources Planning. New York, McGraw-Hill, 1971.

63. James, I. C., B. T. Bower, and N. C. Matalas. Relative Importance of Variables in Water Resources Planning. Water Resources Research. 5(6):1165-1173, 1969.

64. James, L. D. A Case Study in Income Redistribution from Reservoir Construction. Water Resources Research. 4(3):499-508, 1968.

65. Johnson, E. L. A Study in the Economics of Water Quality Management. Water Resources Research. 3(2): 291-306, 1967.

66. Kalter, R. J., and L. E. Gosse. Outdoor Recreation in New York State: Projections of Demand, Economic Value, and Pricing Effects. Cornell Univ. Agr. Exp. Station Spec. Series, Vol. 5. Ithaca, Cornell University, 1969.

67. Kalter, R. J., et al. Federal Evaluation of Resource Investments: A Case Study. Agr. Econ. Res. Bull. 313. Ithaca, Cornell University, Water Resources Center and Department of Agricultural Economics, 1970.

68. Kazanoski, Albin D. Treatment of Some of the Uncertainties Encountered in the Conduct of Hydrologic Cost-Effectiveness Evaluation. In: Proceedings of the International Symposium on Uncertainties in Hydrologic and Water Resource Systems, Vol. II. Tucson, University of Arizona, Dec. 11-14, 1972.

69. Keefer, C. E. No Crash Timetable Involved in Baltimore's $68-Million Plan. Wastes Engineering. Nov. 1960.

70. Kneese, Allen V. Economic and Related Problems in Contemporary Water Resources Management. Natural Resources Journal. 6(3), Oct. 1965.

71. Kneese, A. V., and B. T. Bower. Managing Water Quality: Economics, Technology, Institutions. Baltimore, The Johns Hopkins Press, 1968.

72. Kneese, A. V., and K. C. Nobe. The Role of Economic Evaluation in Planning for Water Resource Development. Nat. Resources Journal. 2:456-457, Dec. 1962.

73. Ko, S. C., and L. Duckstein. Cost-Effectiveness Analysis of Wastewater Reuses. Journal of the Sanitary Engineering Division, ASCE. Proceedings Paper 9434. 98(SA6):869-881, Dec. 1972.

74. Koenig, L., and D. Ford. Reuse Can Be Cheaper than Disposal. Chemical Engineering Progress Symposium Series. 63(78):143-147, 1967.

75. Krutilla, J. V. The Columbia River Treaty: The Economics of an International River Basin Development. Baltimore, The Johns Hopkins Press, 1967.

76. Larson, B. O., and H. E. Hudson, Jr. Residential Water Use and Family Income. Journal of the American Water Works Association. pp. 603-611, 1951.

77. Lee, Robert R. Local Government Public Works Decision-Making. Stanford University, Institute in Engineering Economic Systems, Stanford. Report No. EEP-9. 1964.

78. Leopold, L. B. Quantitative Comparison of Some Aesthetic Factor Among Rivers. U.S. Geological Survey Circ. 620. Washington, D.C.

79. Linaweaver, F. P., Jr., J. C. Geyer, and J. B. Wolff. A Study of Residential Water Use. Department of Housing and Urban Development, Technical Studies Program of the Federal Housing Administration, Washington, D.C., Feb. 1967.

80. Linaweaver, F. P., Jr., J. C. Geyer, and J. B. Wolff. Final and Summary Report on the Residential Water Use Project. Baltimore, Johns Hopkins University, Department of Environmental Engineering Science, July 1966.

81. Marglin, Stephen A. Approaches to Dynamic Investment Planning. Amsterdam, North Holland Publishing Co., 1963.

82. Marglin, Stephen A. Public Investment Criteria. Cambridge, The Massachusetts Institute of Technology Press, 1966.

83. Marglin, Stephen A. Public Investment Criteria. Cambridge, The Massachusetts Institute of Technology Press, 1967.

84. Marglin, S. A. Public Investment Criteria: Benefit-Cost Analysis Planned Economic Growth. Cambridge, The Massachusetts Institute of Technology Press, 1968.

85. Marks, R. H. Waste Water Reclamation: A Practical Approach for Many Water Short Areas. Power. 107(11): 47-50, 1963.

86. McKean, Roland N. Efficiency in Government Through Systems Analysis, With Emphasis on Water Resources Development. New York, John Wiley and Sons, 1958.

87. Metcalf, L. Effect of Water Rates and Growth in Population Upon Per Capita Consumption. Journal of the American Water Works Association. pp. 1-21, Jan. 1926.

88. Methodology for Economic Evaluation of Municipal Water Supply-Wastewater Disposal Including Considerations of Seawater Distillation and Wastewater Renovation. Office of Saline Water and Federal Water Quality Administration, 1970.

89. Moore, C. L., et al. Economic Evaluation of Alternative Farm Water Sources in the Claypan Area of Illinois. University of Illinois Resources Center #6.

90. Moore, C. V., and T. R. Hedges. Economics of On-Farm Irrigation Availability and Costs and Related Farm Adjustments: Farm Size Relation to Resource Use, Earnings, and Adjustments on the San Joaquin Eastside. California Agricultural Experiment Station, Berkeley. Research Report 263. 1963.

91. Morgan, W. Douglas. A Time Series Demand for Water Using Micro Data and Binary Variables. Water Resources Bulletin. Aug. 1974.

92. Morgan, W. Douglas. Residential Water Demand: The Case from Micro Data. Water Resources Research. 9(4):1065-1067, Aug. 1973.

93. New Process Promises Clean Water at Low Cost. Machine Design. 41:14-15, 1969.

94. Olson, J., Jr. The Optimal Allocation of Jurisdictional Responsibility: The Principle of 'Fiscal Equivalence.' In: The Analysis and Evaluation of Public Expenditures: The PPB System, Vol. 1. A medium of papers submitted to the Subcommittee on Economy in Government. U.S. Joint Economic Committee, Washington, D.C., 1969. pp. 321-331.

95. Orcutt, R. D. An Engineering-Economic Analysis of Systems Utilizing Aquifer Storage for the Irrigation of Parks and Golf Courses with Reclaimed Wastewater. University of Nevada Desert Research Institute, Center for Water Resources Research. Technical Report Series H-W. Publication No. 5. 1967.

96. Parker, D. S., and J. A. Crutchfield. Water Quality Management: A Time Profile of Benefits and Costs. Water Resources Research. 4(2):246, 1968.

97. Patterson, W. L., and R. F. Banker. Estimating Costs and Man-power Requirements for Conventional Wastewater Treatment Facilities. Environmental Protection Agency, Washington, D.C., October 1971.

98. Porter, J. W., A. N. Hopkins, and W. L. Fisher. An Economic and Engineering Analysis of Municipal Wastewater Renovation. Chemical Engineering Progress Symposium Series No. 90. 64(246), 1968.

99. Prehn, W. Lawrence, and J. L. McGaugh. Desalting Cost Calculation, Procedures. Office of Saline Water, Washington, D.C. R&D Program Report No. 555. 1971.

100. Proposed Practices for Economic Analyses of River Basin Projects (The Green Book). U.S. Interagency Committee on Water Resources, Washington, D.C., 1958.

101. Protection of the Environment (Title 40). Appendix A: Cost-Effectiveness Analysis. Federal Register. 38(174):24639, Sept. 10, 1973.

102. Renshaw, Edward F. The Demand for Municipal Water. Unpublished Agricultural Economics Seminar Paper. Chicago, University of Chicago, Department of Economics, June 3, 1958.

103. Renshaw, Edward F. Toward Responsible Government: An Economic Appraisal of Federal Investment in Water Resource Programs. Chicago, Idyia Press, 1957.

104. Ridge, Richard. The Impact of Public Water Utility Pricing Policy on Industrial Demand and Reuse, Philadelphia General Electric Company. Technical Information Series. November 1972.

105. Riordan, Courtney. General Multistage Marginal Cost Dynamic Programming Model for the Optimization of a Class of Investment-Pricing Decisions. Water Resources Research. 7(2), April 1971.

106. Riordan, Courtney. Multistage Marginal Cost Model of Investment-Pricing Decisions: Application to Urban Water Supply Treatment Facilities. Water Resources Research. 7(3), June 1971.

107. Sandmo, Agnar. Discount Rates for Public Investment Under Uncertainty. International Economic Review. 15(2), June 1974.

108. Scherer, C. H. Sewage Plant Effluent is Cheaper than City Water. Wastes Engineering. pp. 124-127, 1959.

109. Schmid, A. A., and W. Ward. A Test of Federal Water Project Evaluation Procedures with Emphasis on Regional Income and Environmental Quality: Detroit River, Trenton Navigation Channel. In: Agricultural Economic Review. East Lansing, Michigan State University, April 1970.

110. Schramm, G., and R. E. Burt, Jr. An Analysis of Federal Water Resource Planning and Evaluation Procedures. Ann Arbor, University of Michigan, School of Natural Resources, June 1970.

111. Sewell, W. R. D., et al. Guide to Benefit-Cost Analysis. Ottawa, Canada, Queen's Printer (for Resources for Tomorrow), 1965.

112. Smith, Robert. A Compilation of Cost Information for Conventional and Advanced Wastewater Treatment Plant and Processes. Federal Water Quality Administration, October 1967.

113. Smith, Robert. Costs of Wastewater Renovation. Environmental Protection Agency, Washington, D.C., 1971.

114. Smith, R., et al. A Compilation of Cost Information for Conventional and Advanced Wastewater Treatment Plants and Processes. Environmental Protection Agency, Washington, D.C., 1972.

115. Smith, R., et al. Cost to the Consumer for Collection and Treatment of Wastewater. Environmental Protection Agency, Washington, D.C., July 1971.

116. Smith, Robert, E. Smith, and R. Richard. Cost to the Consumer for Collection and Treatment of Wastewater. Environmental Protection Agency, Washington, D.C., 1970.

117. Southern District Urban Per Capita Water Use Study, 1960-1970. California Department of Water Resources, Southern District. Memorandum report. 1972.

118. Stone, R. V., H. B. Gotaas, and V. W. Bacon. Economic and Technical Status of Water Reclamation from Sewage and Industrial Wastes. Journal of the American Water Works Association. 44:503-517, 1952.

119. Timmons, John F., and J. R. Prescott. Development of Model for Pricing Water in Providing a Basis for Allocating Water Among Competing Uses. Iowa State University, November 1972.

120. Turnovsky, Stephen J. The Demand for Water: Some Empirical Evidence on Consumer's Response to a Commodity Uncertain in Supply. Water Resources Research. 5(2):350-361, April 1969.

121. Unger, Samuel G., M. J. Emerson, and D. L. Jordening. State-of-Art Review: Water Pollution Control Benefits and Costs. Environmental Protection Agency, Washington, D.C., October 1973.

122. Upton, C. Application of User Charges to Water Quality Management. Water Resources Research. 7(2):264-272, 1971.

123. Van Vuuren, L. R. J., and M. R. Henzen. Process Selection and Cost of Advanced Wastewater Treatment in Relation to the Quality of Secondary Effluents and Quality Requirements for Various Uses. Progress in Water Technology, Vol. I, Applications of New Concepts of Physical-Chemical Wastewater Treatment. New York, Pergamon Press, 1972.

124. Wallace, L. T. The Economic Demand for Water in Urban Areas. In: California Water, A Study in Resource Management. Seckler, D. (ed.). Berkeley, Los Angeles, London, University of California Press, 1971. p. 41.

125. Ware, James E., and R. M. North. The Price and Consumption of Water for Residential Use in Georgia. Bureau of Business and Economic Research, School of Business Administration, Georgia State College, Atlanta, Georgia. Research Paper No. 40. October 1967.

126. Warford, J. J. Water Requirements: The Investment Decision in the Water Supply Industry. In: The Manchester School of Economics and Social Studies, Vol. 34 (I). Manchester University, England, Jan. 1966. pp. 87-112.

127. Watson, I. C. Manual for Calculation of Conventional Water Treatment Costs. U.S. Department of the Interior, Office of Saline Water, Washington, D.C., March 1972.

128. Weisbrod, B. A. Income Redistribution Effects and Benefit Cost Analysis. In: Problems in Public Expenditure Analysis, Chase, S. B., Jr. (ed). Washington, D.C., The Brookings Institution, 1968.

129. Werner, R. R. An Investigation of the Employment of Multiple Objectives in Water Resources Planning. Ph.D. thesis. Brookings, South Dakota State University, 1968.

130. Whinston, A. B. Economic Analyses of Optimal Water Quality Management. Indiana Water Resources Research Center #25, August 1972.

131. Wilson, C. W., and R. P. Cantrell. A Study of the Technical and Economic Feasibility of Using Sewage Effluent for Irrigation in Lincoln Parish, La. 1969.

132. Wollman, Nathaniel (ed.). The Value of Water in Alternative Uses. Albuquerque, University of New Mexico Press, 1962.

133. Wong, S. T. A Model on Municipal Water Demand: A Case Study of Northeastern Illinois. Land Economics. 48(1):34-44, February 1972.

134. Wong, S. T., J. R. Sheaffer, and H. B. Gotaas. Multivariate Statistical Analysis of Water Supplies. (Presented at the American Society of Civil Engineers, Water Resources Engineering Conference, Milwaukee, Wisconsin, May 1963.).

135. Young, Robert A. Price Elasticity of Demand for Municipal Water: A Case Study of Tucson, Arizona. Water Resources Research, 9(4):1068-1072, August 1973.

GENERAL

1. Abelson, P. H. An Overall Look at Water Resources. Chemical Engineering Progress Symposium Series. 63(78):96, 1967.
2. Aitken, I. M. E. Solute Control in Water Reuse. Effluent and Water Treatment Journal. p. 34, 1968.
3. All Round Re-Use of Effluent at Bristol. Water and Waste Treatment Journal. 14(9):10, 1971.
4. Amramy, A. Re-Use of Municipal Waste Water. Civil Engineering. 38(5):58-61, 1968.
5. An Expanding Lubbock ... Reclaimed Water for a Growing City. Lubbock, Texas, City Planning Department, 1969.
6. Anderson, C. M., G. N. Crits, and J. B. Pratt. A New Wastewater Renovation System. Water Works and Wastes Engineering. pp. 28-31, July 1965.
7. Arnold, J. L. Basic Thinking in Water Pollution Control. Water Pollution Control. pp. 601-610, 1971.
8. Bain, J. S., R. E. Caves, and J. Margolis. Northern California's Water Industry, Chapt. 5. Baltimore, The Johns Hopkins Press, 1966.
9. Bargman, R. D., G. W. Adrian, and W. F. Garber. Urban Wastewater Recovery: City of Los Angeles. Chemical Engineering Progress Symposium Series No. 90. 64(216), 1968.
10. Bargman, Robert D., G. W. Adrian, and D. C. Tillman. Planning, Testing, and Design for Water Reclamation for Los Angeles. Paper presented at ASCE National Meeting, Water Resources Engineering, 1973.
11. Barker, J. E., and G. A. Pettit. Water Reuse. Industrial Water Engineering. 5(1):36, 1968.
12. Berger, B. B. The Natural Cycle of Water Reuse. Water and Wastes Engineering. 5(8):34, 1968.
13. Bernstein, M. Water Renovation and the Reuse of Water. The Civil Engineer in South America. 10(8):168, 1968.

14. Bishop, A. B. An Approach to Evaluating Environmental, Social, and Economic Factors in Water Resources Planning. Water Resources Bulletin. (4):724-734, Aug. 1972.

15. Bishop, A. B., and D. W. Hendricks. Analysis of Water Reuse Alternatives in an Integrated Urban and Agricultural Area. Logan, Utah State University, College of Engineering, Utah Water Research Laboratory, Sept. 1971.

16. Bishop, A. B., and D. W. Hendricks. Water Reuse Systems Analysis. Journal of the Sanitary Engineering Division, ASCE, 97(SA 1):41-57, 1971.

17. Bloodgood, D. E. Utilization of Wastewaters. Water and Wastes Engineering. 7:E2-4, 1970.

18. Borneff, J. Die Wiederverwendung von Abwasser. Archiv fur Hygiene und Bakteriologie. 153(4):289-297, 1969.

19. Borneff, J. Die Wiederverwendung von Abwasser. Zentralblatt fur Bakteriologie, Paristitienkunde . . . Abt. Orig. 212:334.

20. Bramer, H. C., and R. D. Hoak. Water Reclamation Chemical Engineering Progress Symposium Series. 63(78):92-95, 1967.

21. Bray, D. T., U. Merten, and M. Augustus. Reverse Osmosis for Water Reclamation. Bulletin, California Water Pollution Control Association. 2(2):11.

22. Brunner, C. A. Pilot-Plant Experiences in Demineralization of Secondary Effluent Using Electrodialysis. Journal, Water Pollution Control Federation. 39:R1, 1967.

23. Bruvold, W. H., and F. C. Ward. Public Attitudes Toward Uses of Reclaimed Wastewater. Water and Sewage Works. 117:120-122, 1970.

24. Bulletin 208. Environmental Protection Agency, Office of Water and Hazardous Materials, Division of Water Planning, Washington, D.C., April 1975.

25. Bunch, R. L., C. W. Chambers, and W. B. Cook. Disinfection of Renovated Wastewater. Federal Water Quality Administration, 1971.

26. Burns & Roe, Inc. Disposal of Brines Produced in Renovation of Municipal Wastewater. Federal Water Quality Administration. Contract No. 14-12-492. May 1970.

27. Butler, C. E. Survival and Recovery of Salmonella in Tucson's Wastewater Reclamation Program. Journal, Water Pollution Control Federation. 41(5):738-744, 1969.

28. California Endorses Wastewater Reuse. Engineering News-Record. 179(10):21, 1967.

29. California Water Reclamation Sites - 1971. California Department of Public Health, Bureau of Sanitary Engineering. 1971.

30. Cecil, L. K. Complete Water Reuse. Chemical Engineering Progress Symposium Series. 63(78):258-261, 1967.

31. Cecil, L. K. How Usable is Present Technology for Removing Nutrients from Wastewater. Progress in Water Technology, Vol. I, Applications of New Concepts of Physical-Chemical Wastewater Treatment. New York, Pergamon Press, 1972.

32. Cecil, L. K. Problems and Practice of Phosphate Removal in Water Reuse. Chemical Engineering Progress Symposium Series. 63(78):159-163, 1967.

33. Cecil, L. K. Sewage Treatment Plant Effluent for Water Re-Use. Water and Sewage Works. 111:421-423.

34. Central Contra Costa Water Renovation Project. Bulletin, California Water Pollution Control Association. 8(2):22, 1971.

35. Channabasappa, K. C. Reverse Osmosis Process for Water Reuse Application. Chemical Engineering Progress Symposium Series No. 97. 1969.

36. Chaty, N. B. Carbon Systems Play Key Role in Advanced Wastewater Treatment. The Flowsheet. (5):4-8, 1972.

37. Clouse, J. L. Need for Water Reuse. Tappi. 47, (Sup. 182A-183A), 1964.

38. Connell, C. H. Utilization of Wastewater to Meet a Shortage of First Water. Industrial Wastes. pp. 148-151, 1957.

39. Connell, C. H., and M. C. Forbes. City Sewage-Plant Effluent is Worth Your Study. Oil and Gas Journal. 59:94-96, 1961.

40. Conservation and Reuse of Used Water. Effluent and Water Treatment Journal. 4:442-443, 1964.

41. Cooper, J. C., and D. G. Hager. Water Reclamation with Granular Activated Carbon. Chemical Engineering Progress Symposium Series. 63(78):185-192, 1967.

42. Copley International Corporation. The Structure of the Southern California Water Industry. Department of the Interior, Office of Water Resources Research. 1974.

43. Cuchetti, Charles J., et al. Benefits or Costs? An Assessment of the Water Resources Council's Proposed Principles and Standards. In: Benefit-Cost and Policy Analysis, Niskanen, W. A., ed. Chicago, Aldme Publishing Co., 1973.

44. Culp, R. L. Wastewater Reclamation by Tertiary Treatment. Journal, Water Pollution Control Federation. p. 799, June 1967.

45. David, E. L. Public Perceptions of Water Quality. Water Resources Research. 7(3):453-457, 1971.

46. Davis, R. K., et al. Conventional and Unconventional Alternatives for Water Supply Management. Water Resources Research. 9(4):861-870, Aug. 1973.

47. Davis, R. K. The Range of Choice in Water Management: A Study of Dissolved Oxygen in the Potomac Estuary. Baltimore, Johns Hopkins Press for Resources for the Future, 1968.

48. Dea, S. J. Total System Concept of Water Pollution Control. Water and Wastes Engineering. 6:36-39, 1969.

49. Deaner, D. G. California Water Reclamation Sites, 1971. California State Department of Public Health, Bureau of Sanitary Engineering.

50. Deaner, D. G. Directory of Wastewater Reclamation Operations in California, 1969. California State Department of Public Health, Bureau of Sanitary Engineering.

51. Deaner, D. G. Public Health and Water Reclamation. Water and Sewage Works. 117:R7-13, 1970.

52. DeLeeuw, A. Waste Water Utilization in the Dam Region. Bulletin of Hydraulic Research, IAHR. 18:174, 1964.

53. Diekmann, S. Veroffentlichungen Instituts fur Siedlungswasserwirtschaft (Water for Bielefeld). (9):5, 1962.

54. Dodson, R. E. San Diego Takes Another Bold Step to Obtain Pure Water from Sewage. American City. 86(2):43, 1971.

55. Dominy, Floyd E. Acquisition of Water from Federal Reclamation Projects for Industrial and Community Development. U.S. Department of the Interior, Bureau of Reclamation, 1969.

56. Dryden, F. D. Mineral Removal by Ion Exchange, Reverse Osmosis, and Electrodialysis. (Paper presented at the Workshop on Wastewater and Reuse. South Lake Tahoe, California. June 1970).

57. Dutt, G. R., and T. W. McCreary. The Quality of Arizona's Domestic Agricultural, and Industrial Waters. University of Arizona Agricultural Experimental Station Report 256. 1970.

58. Dye, E. O. Wastewater Reclamation Project. Water and Sewage Works. 115:139, 1968.

59. Eden, G. E., *et al*. Water from Sewage Effluents. Proceedings and Journal, Institute for Sewage Purification (Brit.), Pt. 5. p. 407, 1966.

60. Effluent Reuse Investigated. Water Works and Wastes Engineering. 1:94, 1964.

61. Effluent Reuse Study at Pudsey. Water and Waste Treatment Journal. 14(6):4, 1971.

62. Elder, C. C. Determining Future Water Requirements. Journal, American Water Works Association. pp. 124-135, Feb. 1951.

63. Eliassen, R., B. M. Wyckoff, and C. D. Tonkin. Ion Exchange for Reclamation of Reusable Supplies. Journal, American Water Works Association. 67:113, 1970.

64. Elliott, J. F., and J. H. Duff. Municipal Supply Augmented by Treated Sewage. Journal, American Water Works Association. pp. 647-650, 1971.

65. Elsahragty, Mohamed Mahmoud. Planning and Operation of Urban Water Quality Management Systems, Vol. IX. Ithaca, Cornell University Water Resources and Marine Sciences Center, Feb. 1974.

66. Evaluation of Land Application Systems. Environmental Protection Agency, Office of Water Programs Operations, Washington, D.C. Technical Bulletin, EPA-430/9-75-001. March 1975.

67. Fair, G. M., and J. C. Geyer. Water Supply and Waste Water Disposal. New York, John Wiley and Sons, 1969.

68. Fair, G. M., J. C. Geyer, and A. D. Okum. Water and Waste Water Engineering, Vol. 2. New York, John Wiley and Sons, 1968.

69. Field Investigation of Wastewater Reclamation in Relation to Groundwater Pollution. Publication No. 6, California State Water Pollution Control Board, 1953.

70. Fiering, M. B., and B. Jackson. Synthetic Streamflows. AGU, Washington, D.C., 1971.

71. Fish, H. Effluent Standards and Water Reuse. Water Pollution Control (London). 68:307, 1969.

72. Flaherty, W. F. Effect of Water Reuse on Stream Quality. Water and Sewage Works. 115:354-357, 1968.

73. Flack, J. E. Urban Water: Multiple Use Concepts. Journal, American Water Works Association. 63:644, 1971.

74. Flack, J. E. Water Rights Transfers--An Engineering Approach. Palo Alto, California, Stanford University, 1965. p. 56.

75. Fleming, R. G. Water Re-Use by Design. American City. 78:106-108, 1963.

76. Fleming, R. G., and H. D. Jobes. Water Reuse: A Texas Necessity. Journal, Water Pollution Control Federation. 41:1564-1569, 1969.

77. Flinn, J. C., and J. C. Day. Towards the Integrated Management of Water Supplies in the Tucson Region of Arizona. Tucson, University of Arizona, Department of Agricultural Economics, June 1972.

78. Flower, W. A., et al. Optimization of Combined Industrial-Municipal Waste Treatment Through Automation and Reuse. Environmental Protection Agency, Washington, D.C., 1972.

79. Foster, Herbert B., Jr., and W. F. Jopling. Rationale of Standards for Use of Reclaimed Water. Journal of the Sanitary Engineering Division, ASCE. 95(SA 3):503, 1969.

80. Fuhrman, R. E. Adaptation of Known Principles and Techniques of Waste Water Management to Specific Environmental Situations and Geographical Conditions. Water Pollution Control (London). 68:619, 1969.

81. Gallagher, E. Water and Sewage Works. 115:356-360, 1968.

82. Gavis, Jerome. Wastewater Reuse. National Water Commission, Arlington, Virginia, 1971.

83. Geraghty, James J., et al. Water Atlas of the United States. Port Washington, N.Y., A Water Information Center Publication, 1973.

84. Geshon, S. I. Unit Water Use Model for the South Coastal Area. Technical Memorandum #27A. California Department of Water Resources, Southern Section, Jan. 1968.

85. Cloyna, E. F., et al. Water Resources Activities in the United States: A Report Upon Present and Prospective Means for Improved Re-Use of Water. 86th Congress, 2d Session, Committee Print No. 30.

86. Gloyna, E. F., W. R. Drynana, and E. R. Hermann. Water Reuse in Texas. Journal, American Water Works Association. 51(6):768-780, 1959.

87. Graesser, H. J. Dallas-Wastewater Reclamation Studies. Journal, American Water Works Association. 63(10):634-640, 1971.

88. Graesser, H. J. The Dallas Philosophy--An Approach to Wastewater Reclamation. Water and Wastes Engineering. 6(9):58.

89. Graesser, H. J., and P. D. Haney. Dallas Builds Center to Study Wastewater Reclamation. Water and Wastes Engineering. 5(12):33, 1968.

90. Gram, A. L., and D. L. Isenberg. Waste Water Treatment. Science Journal. p. 77, 1969.

91. Grant, Robert J. Wastewater Treatment in Great Britain. Water and Sewage Works. 117(8).

92. Griffith, C. O. Conservation of Water by Reuse in Mexico. Chemical Engineering Progress Symposium Series. 63(78):37-40, 1967.

93. Guidance for Facilities Planning, 2nd ed. Environmental Protection Agency, Washington, D.C., October, 1974.

94. Guidelines for Water Quality Management Planning. Environmental Protection Agency, Washington, D.C., 1971.

95. Haney, P. D. Water Reuse for Public Supply. Journal, American Water Works Association. 61(2):73-78, 1969.

96. Hennessey, P. V., L. R. Williams, and Y. S. Lin. Tertiary Treatment of Trickling Filter Effluent in Orange County, California. Journal, Water Pollution Control Federation. 39(11):1819-1933, 1967.

97. Hindin, E., and P. J. Bennett. Water Reclamation by Reverse Osmosis. Water and Sewage Works. 66, 1969.

98. Hirsch, L. Wastewater Reclamation for Water Deficient Lands--Experiences in Southern California. Paper No. 418. International Conference on Water for Peace. Washington, D.C., 1967.

99. Hirshleifer, J. C. DeHaven, and J. W. Milliman. Water Supply: Economics, Technology, and Policy. Chicago, The University of Chicago Press, 1960.

100. Horsefield, David R. Factors in Regional Assessment of Wastewater Reuse. Journal of the American Water Works Association. 66(4):238-239, April 1974.

101. Houser, E. W. Santee Project Continues to Show the Way. Water and Wastes Engineering. 7(5):40-44, 1970.

102. Hulschmidt, M., and M. Fiering. Simulation Techniques for Design of Water Resource Systems. Boston, Harvard University Press, 1966.

103. Ide, T., N. Matsumoto, and H. Armitsu. Utilization of Municipal Wastewater in Japan. Chemical Engineering Progress Symposium Series. 63(78):46-53, 1967.

104. Ikonnikova, S. Purification of Municipal Water Supplies in the U.S.S.R. Water and Waste Treatment. p. 535, 1964.

105. Improved Sewage By-Product Reclamation. Fluid Handling. (88):150, 1957.

106. Improving Water Quality Management Planning in Nonmetropolitan Areas. Environmental Protection Agency, Office of Air and Water Programs, Washington, D.C., January 1973.

107. Ingraham, H. S. Regional Planning for Water Supply and Sewage Treatment. Archives of Environmental Health. 16, 1968.

108. James, I. C., B. T. Bower, and N. C. Matalas. Relative Importance of Variables in Water Resources Planning. Water Resources Research. 5(6):1165-1173, 1969.

109. Johnson, J. F. Renovated Waste Water: An Alternative Source of Municipal Water Supply in the United States. Chicago, University of Chicago, Department of Geography, 1971.

110. Kardos, L. T. A New Prospect. Environment. 12(2):10, 1970.

111. Keefer, C. E. Tertiary Sewage Treatment. Public Works. 93(11):109-112; (12):81-83, 1962.

112. Kneese, A. V., and B. T. Bower. Managing Water Quality: Economics, Technology, Institutions. Baltimore, The Johns Hopkins Press, 1968.

113. Koebig and Koebig, Inc. Wastewater Reclamation in Southern California Coastal Area. Los Angeles Area Chamber of Commerce, Wastewater Reclamation Task Force: Draft report. 1972.

114. Krutilla, J. V. Conservation Reconsidered. American Economic Review. 57:777-786, 1967.

115. Krutilla, J. V., and O. Eckstein. Multiple Purpose River Development. Baltimore, The Johns Hopkins Press, 1958.

116. Langbein, Walter B. Municipal Water Use in the United States. Journal of the American Water Works Association. pp. 997-1001, Nov. 1949.

117. Law, J. P., Jr., et al. Water Quality Management Problems in Arrid Regions. U.S. Department of the Interior, Federal Water Quality Administration, Washington, D.C., 1970.

118. Leopold, L. B. Quantitative Comparison of Some Aesthetic Factor Among Rivers. U.S. Geological Survey Circ. 620. Washington, D.C.

119. Leopold, L. B., and M. O'Brien Marchand. On the Quantitative Inventory of the Riverscape. Water Resources Research. 4(4):709-718, 1968.

120. Levy, D., and V. J. Calise. Fresh Water from Sewage. Consulting Engineer. 12(1):100-105, 1959.

121. Libya, Ministry of Agriculture. Water Resources in Libya: Their Investigation, Development, and Improvement. Paper No. 614. (International Conference on Water for Peace. Washington, D.C., 1967.)

122. Linstedt, D. Evaluation of Treatment for Urban Wastewater Reuse. Environmental Protection Agency, Washington, D.C., 1973.

123. Linstedt, D., et al. Metropolitan Successive Use of Available Water. Journal, American Water Works Association. 63:610, 1971.

124. Linstedt, D. Quality Considerations in Successive Water Use. Journal, Water Pollution Control Federation. 43:1681-1694, 1971.

125. Lubzens, Michael. Wastewater Treatment Plant Operational Problems at Haifa, Israel. Journal, Water Pollution Control Federation. 41(3):413-417, 1969.

126. Maass, Arthur, et al. Design of Water-Resource Systems. Cambridge, Harvard University Press, 1962.

127. MacIver, Ian. Urban Water Supply Alternatives. Research Paper No. 126. Chicago, The University of Chicago, Department of Geography, 1970.

128. Marks, R. H. Waste Water Reclamation: A Practical Approach for Many Water Short Areas. Power. 107(11): 47-50, 1963.

129. McGauhey, P. H. Engineering Management of Water Quality. New York, McGraw-Hill, 1968.

130. McGauhey, P. H. The Why and How of Sewage Effluent Reclamation. Water and Sewage Works. 104:265-270, 1957.

131. McGauhey, P. H., and J. E. Middlebrooks. Wastewater Management. Water and Sewage Works. 119(7):49-53, 1972.

132. McKee, J. E. Potential for Reuse of Wastewater in North Central Texas. Water Resources Bulletin. 7(4):740-749, 1969.

133. McKee, J. E., and H. W. Wolf (eds.). Water Quality Criteria. California State Water Resources Control Board. Publication No. 3-A. 1971.

134. Merten, U., and D. T. Bray. Reverse Osmosis for Water Reclamation. (International Conference on Water Pollution Research. Munich, Germany. 1966.)

135. Merz, R. C. Direct Utilization of Waste Waters. Water and Sewage Works. 103:417-423, 1956.

136. Metzler, D. F. Wastewater Reclamation as a Water Resource. (87th Annual Conference of American Water Works Association. 1967.)

137. Middleton, F. M. Advanced Treatment of Waste Waters for Reuse. Water and Sewage Works. 3(9):401-410, 1964.

138. Middleton, F. M. Concepts of Waste Water Reuse. Water and Sewage Works. 118:59-62, 1971.

139. Middleton, F. M. Waste Water Treatment for Return to Natural Cycle Reuse. Water and Wastes Engineering. 5:61-64, 1968.

140. Miller, D. G., and D. H. Newsome. Conservation of Water by Reuse in the United Kingdom. Chemical Engineering Progress Symposium Series. 63(78):13-31, 1967.

141. Milliman, Jerome W. Policy Horizons for Future Urban Water Supply. Land Economics. pp. 109-132, May 1963.

142. Miyahara, Shoza, and T. Ando. Tertiary Treatment of Sewage Water. Sangyo Kogai. 6(8):454, 1970.

143. Murray, C. Richard. Water Use in the United States in 1965. Journal of the American Water Works Association. 61(11):567-571, Nov. 1969.

144. National Technical Advisory Committee to the Secretary of the Interior. Water Quality Criteria. Federal Water Pollution Control Agency, Washington, D.C., 1968.

145. New Sewage Treatment Works for Exeter England. Local Government Technology. 137(4118):30-33, 1971.

146. New Technology for Treatment of Wastewater by Reverse Osmosis. Environmental Protection Agency, Washington, D.C., 1970.

147. Nierstrasz, H. Cyclic Waste Recovery Systems. Water Pollution Control (Canada). 109(11):33.

148. 1968 Inventory, Municipal Waste Facilities. Environmental Protection Agency, Washington, D.C. Publication No. OWF-1. 1971.

149. O'Farrell, T. P., D. F. Bishop, and S. M. Bennett. Advanced Waste Treatment at Washington, D.C. Chemical Engineering Progress Symposium Series. 65(97):251, 1969.

150. Okun, D. A. New Directions for Wastewater Collection and Disposal. Journal of the Water Pollution Control Federation. 43(11):2171-2180, 1971.

151. Ottoboni, A., and A. E. Greenberg. Toxicological Aspects of Wastewater Reclamation. Journal of the Water Pollution Control Federation. 42:493-499, 1970.

152. Parizek, R. R. Wastewater Renovation and Conservation. Public Works. 99:130, 1968.

153. Parker, Clinton E. Feasibility of Water Reuse at Highway Rest Stations. Journal of the American Water Works Association. 66(4):247-249, April 1974.

154. Parker, D. S., and J. A. Crutchfield. Water Quality Management: A Time Profile of Benefits and Costs. Water Resources Research. 4(2):246, 1968.

155. Parkhurst, J. D. Practical Application for Reuse of Wastewater. Chemical Engineering Progress Symposium Series. 64(90):225-231, 1968.

156. Parkhurst, J. D. Reclaiming Used Water. American City. 78:83-85, 1963.

157. Parkhurst, J. D. Waste Water Reuse -- A Supplemental Supply. Journal of the Sanitary Engineering Division, ASCE. 96(SA 3), Jan. 1970.

158. Parkhurst, J. D. Water Utility Concept Applied in Water Reuse. Public Works. 98(10):110-112, 200, 202, 1967.

159. Parkhurst, J. D., C. W. Carry, A. N. Masse, and J. N. English. Practical Applications for Reuse of Wastewater. Chemical Engineering Progress Symposium Series No. 90. 64(225), 1968.

160. Parkhurst, J. D., C. L. Chen, C. W. Carry, and A. N. Masse. Demineralization of Wastewater by Ion Exchange. (Paper presented at the 5th International Conference on Water Pollution Research. San Francisco, California. August 1970.)

161. Peter, I. Y. Sewage Effluent into Sand Dunes. Water and Sewage Works. 105:493, 1958.

162. Petters, J. H., and D. Cuming. Water Conservation by Barrier Injection. Water and Sewage Works. 114(2):63, 1967.

163. Phillips, J. D., and G. L. Shell. Pilot Plant Studies of Effluent Reclamation. Water and Wastes Engineering. 6:38-41, 1968.

164. Phillips, William J. The Direct Reuse of Reclaimed Wastewater: Pros, Cons, and Alternatives. Journal of the American Water Works Association. 66(4):231-237, April 1974.

165. Plan of Study, Susquehanna River Basin Study. U.S. Army Corps of Engineers. U.S. Army Engineer District, Baltimore, Maryland, 1965.

166. Pollio, F. X., and R. Kunin. Tertiary Treatment of Municipal Sewage Effluents. Environmental Science and Technology. 2:54, 1968.

167. Porter, J. W. Planning of Municipal Wastewater Renovation Projects. Journal of the American Water Works Association. 62:543,548, 1970.

168. Ranganathan, G. S. The Use and Disposal of Water in India. Effluent and Water Treatment Journal. (10):517, 1968.

169. Rawn, A. M., et al. Integrating Reclamation and Disposal of Waste Water. Journal of the American Water Works Association. 45(5), 1963.

170. Reclaimed Water Solves International Problem. Journal of the Sanitary Engineering Division, ASCE. 89(SA 3):12-13, 1963.

171. Recommended Methods for Water-Data Acquisition. U.S. Department of the Interior, Federal Interagency Work Group on Designation of Standards for Water Data Acquisition, Washington, D.C., 1972.

172. Report to the Water Resources Council by the Special Task Force: Principles for Planning Water and Land Resources. U.S. Water Resources Council, Washington, D.C., 1970.

173. Report to the Water Resources Council by the Special Task Force: Standards for Planning Water and Land Resources. U.S. Water Resources Council, Washington, D.C., 1970.

174. Report to the Water Resources Council by the Special Task Force: Findings and Recommendations. U.S. Water Resources Council, Washington, D.C., 1970.

175. The Reuse of Water. West Texas Today. 45(9):12, 22-23, 1964.

176. Reverse Osmosis for Wastewater Treatment. Gulf General Atomic, Inc., San Diego, California. No. GA-8020. 1967.

177. The Reverse Osmosis Process and Its Potential for Application in Water and Waste Treatment. Rex Chainbelt, Inc. International Project Report No. OP-4 (J-20, 904)-1. 1968.

178. Reverse Osmosis Renovation of Municipal Wastewater. Federal Water Quality Administration, 1969.

179. Rickles, R. N. Conservation of Water by Reuse in the United States. Chemical Engineering Progress Symposium Series. 63(78):74-87, 1967.

180. Russell, C. S., D. Arey, R. Kates. Drought and Water Supply: Of the Massachusetts Experience for Municipal Planning. Baltimore, The Johns Hopkins Press, 1971.

181. Scherer, C. H. Effluent Reuse in Amarillo. American Institute of Chemical Engineers. (Presented at Complete Water Reuse Meeting. Washington, D.C., April 1970.)

182. Schmidt, C., and E. Clements. Demonstrated Technology and Research Needs for Reuse of Municipal Wastewater. Environmental Protection Agency, Washington, D.C. Contract No. 68-03-0148. 1974.

183. Sebastian, F. P. Wastewater Reclamation and Reuse. Water and Wastes Engineering. 7(7), 1970.

184. Seidel, H. F., and E. R. Baumann. A Statistical Analysis of Water Works Data for 1955. Journal of the American Water Works Association. pp. 1531-1566, December 1957.

185. Shuvel, H. I. Proceedings of the Jerusalem International Conference on Water Quality and Pollution Research. Ann Arbor, Humphrey Science Publishers, 1970.

186. Shuvel, H. I. Water Pollution Control in Semi-Arid and Arid Zones. Water Research. 1(4):297, 1967.

187. Slack, J. G. Sewage Effluent Treatment for Water Recovery. Effluent and Water Treatment Journal. 9:257, 1969.

188. Smith, J. M., A. N. Masse, and R. P. Miele. Renovation of Municipal Wastewater by Reverse Osmosis. Environmental Protection Agency, Washington, D.C., 1970.

189. Sontheimer, H. Die Wiederverwendung von Abwasser. Umschau in Wissenschaft und Technik. (7):195-200, 1968.

190. Sopper, W. E. Waste Water Renovation for Reuse; Key to Optimum Use of Water Resources. Water Research. 2:471, 1968.

191. Sosewitz, B., and V. W. Bacon. Chicago's First Tertiary Treatment Plant. Water and Wastes Engineering. 5(9):52, 1968.

192. Sprowl, Tom M., and R. M. Hopkins. Tertiary Wastewater Treatment Made Practical. The American City. p. 65, April 1972.

193. Stanbridge, H. H. From Pollution Prevention to Effluent Re-Use. Water and Sewage Works. *111*:446-452, 494-499, 1964.

194. Stander, G. J. Tertiary Treatment - The Corner Stone of Water Quality Protection and Water Resources Optimization. Progress in Water Technology, Vol. I, Applications of New Concepts of Physical-Chemical Wastewater Treatment. New York, Pergamon Press, 1972.

195. Stander, G. J., *et al*. Current Status of Research on Waste Water *Reclamation* in South Africa. Water Pollution Control (London). *70*(2):213-222, 1971.

196. Stander, G. J., and A. J. Clayton. Planning and Construction of Waste Water Reclamation Schemes as an Integral Part of Water Supply. Water Pollution Control (London). *70*:228, 1971.

197. Stander, G. J., and J. W. Funke. Conservation of Water by Reuse in South Africa. Chemical Engineering Progress Symposium Series. *63*(78):1-2, 1967.

198. State Health Department Proposes Criteria for Reclamation Reliability. Bulletin, California Water Pollution Control Association. *10*(4):30-32, 1974.

199. Stenburg, R. L., *et al*. New Approaches to Wastewater Treatment. *Journal of* the Sanitary Engineering Division, ASCE. *94*:1121-1136, 1968.

200. Stenburg, R. L., *et al*. New Approaches to Wastewater Treatment. *Journal of* the Sanitary Engineering Division. ASCE. *95*:978-982 1969.

201. Stenburg, R. L., *et al*. New Approaches to Wastewater Treatment. *Journal of* the Sanitary Engineering Division. ASCE. *96*:613-615, 1970.

202. Stephen, D. G. Renovation of Municipal Wastewater for Reuse. American Institute of Chemical Engineers Symposium Series. *9*, 1965.

203. Stephen, D. G. Water Renovation--Advanced Treatment Processes. Civil Engineer. *35*:46, 1965.

204. Stephen, D. G., and R. B. Schaffer. Wastewater Treatment and Renovation Status of Process Development. Journal Water Pollution Control Federation. 42:399-410, 1970.

205. Stephan, D. G., and L. W. Weinberger. Wastewater Reuse - Has It 'Arrived'? Journal of the Water Pollution Control Federation. 40(4):529-539, 1968.

206. Stevens, J. I. Present and Future Disposal of Sludges from Water Reuse. Chemical Engineering Progress Symposium Series. 63(78):250, 1967.

207. Suhr, L. G. Some Notes on Reuse. Journal of the American Water Works Association. 63:630, 1971.

208. Susquehanna River Basin Study Plan: A Review of Alternatives. U.S. Department of the Army, Washington, D.C., 1966.

209. Symons, G. E. 2020 Vision: A Look at Wastewater Disposal 50 Years Hence. Water and Wastes Engineering.

210. Symposium on Wastewater Treatment and Reuse. Effluent and Water Treatment Journal. p. 94, 1969.

211. Taras, M. J. Water Guide to Europe. Water and Sewage Works. January 1969.

212. Telfer, J. G. The Medical Professions' Attitude Toward Water Reuse. Chemical Engineering Progress Symposium Series. 63(78):101, 1967.

213. Thompson, R. G., M. Z. Hyatt, J. W. McFarland, and H. P. Young. Forecasting Water Demands. The National Water Commission.

214. Tischler, L. F., and S. C. Burnitt. Wastewater Reclamation and Reuse. Texas State Water Development Board, Austin, Texas, 1971.

215. Todd, D. K., (ed.). The Water Encyclopedia. Port Washington, N.Y., Water Information Center, 1970.

216. Truesdale, G. A. Water Pollution Control: Need and Trends. Water Pollution Control. pp. 644-649, 1971.

217. Unger, J. Chinese Turning Old Waste Material to New Uses. Christian Science Monitor. p. 15, March 22, 1972.

218. Use of Ozone in Reclamation of Water from Sewage Effluent. Surveyor and Municipal Engineer. 131(3947):21-22, 1968.

219. Van Der Goot, H. A. Water Reclamation Experiments at Hyperion. Sewage and Industrial Wastes. 29(10):1139-1144, 1957.

220. Vandertulip, J. J. Return Flows: A reusable Water Resource. Chemical Engineering Progress Symposium Series. 63(78):106, 1967.

221. Viessman, W., Jr. Developments in Waste Water Re-Use. Public Works. 96(4):138-140, 1965.

222. Viewing Water Renovation and Reuse in Regional Water Resources Systems. Water Resources Research. 3(1), 1967.

223. Viraraghavan, T. Sewage Treatment with Special Reference to Use on Land for Irrigation. Institution of Engineers (India). 50(2):25-28, 1969.

224. Wastewater Reclamation and Reuse - Morro Bay Area. John Carollo Engineers, San Luis Obispo County, California, 1962.

225. Water from Raw Sewage. Chemistry and Engineering News. 49:11, 1971.

226. Water Policies for the Future. National Water Commission, Washington, D.C., 1973.

227. Water Quality Criteria: Report of the National Technical Advisory Committee to the Secretary of the Interior. Federal Water Quality Administration, Washington, D.C., 1968.

228. Water Resources Management Study, South Coast - Santa Barbara County. Toups Corporation, Santa Barbara, California, 1974.

229. Water Reused on Pike's Peak. Public Works. 83(11):114, 1970.

230. When Waste Disposal Taxes Water Supply, Reclamation is Key to Treatment. Engineering News. 173:41-42, 1964.

231. Watson, J. L. A. Oxidation Ponds and Use of Effluent in Israel. Effluent and Water Treatment Journal. 3:150-153, 1963.

232. Weber, W. J., Jr., and F. A. DiGiano. Reclamation of Water for Reuse as a Water Resource. (International Conference on Water for Peace, Washington, D.C., 1967.) Paper 393.

233. Weir, E. Notes on Water Pollution Control. Water Pollution Control. pp. 212-216, 1969.

234. Weismantel, G. E. Denver Aims at Total Reuse. Chemical Engineer. 78:82, 1971.

235. Wesner, G. M., and R. L. Culp. Wastewater Reclamation and Seawater Desalination. Journal of the Water Pollution Control Federation. p. 1932, October 1972.

236. Whetstone, G. A. Potential Reuse of Effluent as Factor in Sewage Design. Chemical Engineering Progress Symposium Series. 63(78):255-257, 1967.

237. Whetstone, G. A. Re-Use of Effluent in the Future. Texas Water Development Board, Austin, Texas, 1965.

238. White, Gilbert. Strategies of American Water Management. Ann Arbor, University of Michigan Press, 1969.

239. Whitford, Peter W. Residential Water Demand Forecasting. Water Resources Research. 8(4):829-839, August 1972.

240. Wiessman, W., Jr. Developments in Waste Water Re-Use. Public Works. 96:138-140, 1965.

241. Zuckerman, M. M., and A. H. Molof. High Quality Reuse Water by Chemical-Physical Wastewater Treatment. Journal of the Water Pollution Control Federation. 42:437-456, 1970.

GROUNDWATER RECHARGE

1. Baffa, J. J., and N. J. Bartilucci. Wastewater Reclamation by Groundwater Recharge on Long Island. Journal, Water Pollution Control Federation. 39(3):431-438, 1967.

2. Baffa, J. J., et al. Development in Artificial Ground Water Recharge. Welling Water. Nov. 1968.

3. Boen, D. F., J. H. Bunts, Jr., and R. J. Currie. Study of Reutilization of Wastewater Recycled Through Groundwater, Vols. I and II. Hemet, California, Eastern Municipal Water District, 1971.

4. Bouwer, Herman, R. C. Rice, and E. D. Escarcega. Renovating Secondary Sewage by Ground Water Recharge with Infiltration Basins. Environmental Protection Agency, Washington, D.C., 1972.

5. Bouwer, Herman. Ground Water Recharge Design for Renovating Waste Water. Journal of Sanitary Engineering Division, ASCE. 97(SA 1):59-74, 1970.

6. Gould, B. W. Wastewater Reclamation Using Groundwater Recharge. Effluent and Water Treatment Journal. 11(2):88-90, 94-95; (3):139-143, 1971.

7. Kincannon, D. F., and W. G. Tiederman. Water Reclamation for Ground Water Recharge. Completion Report, OWRR A-034-OKLA-Cl. June 1972.

8. Krone, R. B., P. H. McGauhey, and H. B. Gotaas. Direct Recharge of Ground Water with Sewage Effluents. Journal of the Sanitary Engineering Division, ASCE. 83(SA 4), 1957.

9. Matlock, W. G. Sewage Effluent Recharge in an Ephemeral Channel. Water and Sewage Works. 113:(6):224-229, 1966.

10. Matlock. W. G., and P. R. Davis. Groundwater in the Santa Cruz Valley. Univ. of Arizona Agric. Exp. Sta. Technical Bulletin 194. 1972.

11. Nassau Activates Recharge Plant. Water in the News. 7, 1967.

12. Owen, L. W. Ground Water Management and Reclaimed Water. Journal of the American Water Works Association. 60(2):135-144, 1968.

13. Peters, J. H., and J. L. Rose. Water Conservation by Reclamation and Recharge. Journal of the Sanitary Engineering Division, ASCE. 94(SA 4):625-639, 1968.

14. Reclaimed Wastewater May Fill a Salt Free Aquifer. Engineering News-Record. 179(6):38, 1967.

15. Rose, John L. Injection of Treated Wastewater into Aquifers. Water and Wastes Engineering. p. 40, October 1968.

16. Simins, H. J. Advanced Waste Treatment for Water Reclamation and Reuse by Injection. Nassau Co., Department of Public Works, Mineola, N.Y.

17. Sopper, W. E. Renovation of Municipal Sewage Effluent for Groundwater Recharge Through Forest Irrigation. International Conference on Water for Peace, Washington, D.C. Paper No. 571. 1967.

18. Stevens, D. B., and J. Peters. Long Island Recharge Studies. p. 2009, 1966.

19. Todd, D. K. Groundwater Hydrology. Wiley & Sons, 1959.

20. Wesner, G. M., and D. C. Baier. Injection of Reclaimed Wastewater Into Confined Aquifer. Journal of the American Water Works Association. 62:203-210, 1970.

21. Williams, Roy E., and D. D. Eier, and A. T. Wallace. Feasibility of Re-Use of Treated Wastewater for Irrigation, Fertilization and Ground-Water Recharge in Idaho. Idaho Bureau of Mines and Geology, Moscow, 1969.

INDUSTRIAL REUSE

1. Banks, H. O., et al. Economic and Industrial Analysis of Wastewater Reclamation and Reuse Projects. San Francisco, Leeds, Hill & Jewett, 1971.

2. Bower, Blair T. The Economics of Industrial Water Utilization. Water Research, Baltimore, The Johns Hopkins Press, 1966. pp. 143-173.

3. Bradakis, H. L. Joint Municipal Industry Spray Irrigation Project. Industrial Water and Wastes. 6(4):117-120, 1961.

4. Can We Use Treated Sewage in Our Boilers? Power. 111:170-171, 1967.

5. Connell, C. H., and E. J. M. Berg. Industrial Utilization of Municipal Waste Water. Sewage and Industrial Wastes. 31:212-220, 1959.

6. Connell, C. H., and E. J. M. Berg. Practice and Potentials in Industrial Utilization of Municipal Waste Water. (Proceedings, 13th Industrial Waste Conference at Purdue University. pp. 227-242, 1958.).

7. Connell, C. H., and E. J. M. Berg. Reclaiming Municipal Waste Water for Industrial and Domestic Re-Use. Southwest Water Works Journal. 41:17-19, 1960.

8. Connell, C. H., and M. C. Forbes. Once-Used Municipal Water as Industrial Supply. Water and Sewage Treatment. 3(9):397-400, 1964.

9. Cootner, Paul H., and G. O. G. Lof. Water Demand for Steam Electric Generation, An Economic Projections Model. Baltimore, Johns Hopkins Press, Resources for the Future, 1965. pp. 34-35.

10. Dominy, Floyd E. Acquisition of Water from Federal Reclamation Projects for Industrial and Community Development. U.S. Department of the Interior, Bureau of Reclamation, 1969.

11. Dutt, G. R., and T. W. McCreary. The Quality of Arizona's Domestic, Agricultural, and Industrial Waters. Univ. of Arizona Agricultural Experimental Station Report 256. 1970.

12. Eller, J., *et al*. Water Reuse and Recycling in Industry. *Journal*, American Water Works Association. *62*:149, 1970.

13. Eynon, D. Wastewater Treatment and Reuse of Treated Sewage as an Industrial Water Supply. The Chemical Engineer. p. 6, 1970.

14. Flower, W. A., *et al*. Optimization of Combined Industrial-*Municipal* Waste Treatment Through Automation and Reuse. Environmental Protection Agency, Washington, D.C., 1972.

15. Funke, J. W. A Guide to Water Conservation and Water Reclamation in Industry. National Institute for Water Research, Pretoria, South Africa. CSIR Guide K9.

16. Garland, C. F. Waste Water Reuse in Industry. Water and Sewage Works. *114*:R204, 1967.

17. Gloyna, E. F., *et al*. Water Reuse in Industry. Journal, Water *Pollution* Control Federation. p. 237, 1970.

18. Gomez, H. J. Water Reuse at the Celulosa y Derivados, S. A. Plants. Proceedings, 23d Industrial Waste Conference. Purdue University Extension Series. *53*:165, 1969.

19. Guiver, K., and R. Huntingdon. A Scheme for Providing Industrial Water Supplies by the Re-Use of Sewage Effluent. Water Pollution Control (London). *70*:75, 1971.

20. Haack, J. E. Treatment of Sewage for Industrial Utilization at Moose Jaw. Municipal Utilities. *90*(10): 20, 36-41.

21. Hauser, Frank R. Expansion of Industrial Water Facilities at Sparrows Point. Iron and Steel Engineer. Sept. 1956.

22. Hill, William P. Industry Converts Sewage Works Effluent into Water Supply. Water Works and Sewage. Dec. 1945.

23. Humphrey, F. C. Sewage Effluent in Use as Power Plant Circulating Water. (Proceedings of 14th Industrial Waste Conference.) Purdue University. 1959. pp. 732-742.

24. Industry Utilizes Sewage and Wastes Effluents for Processing Operations. Wastes Engineering. 28(9):444-448, 467, 1957.

25. Janacek, K. F. Treated Sewage as Boiler Make-Up. Industrial Water Engineering. 2(12), 1966.

26. Jenkins, S. H. Composition of Sewage and Its Potential Use as a Source of Industrial Water. Chemistry and Industry. pp. 2072-2079, 1962.

27. Jensen, L. C., and C. F. Renn. Use of a Tertiary Treated Sewage as Industrial Process Waters. Water and Sewage Works. 115:184, 1968.

28. Johnson, W. H. Treatment of Sewage Plant Effluent for Industrial Reuse. (International Water Conference.) 1964.

29. Johnson, W. H. Water Treatment and Reclamation in Steel Plants. Iron and Steel Engineering. 40:142-147, 1963.

30. Keating, R. J., and V. J. Calise. Treatment of Sewage Effluent for Industrial Re-Use. Sewage and Industrial Wastes. 27(7):763-782, 1955.

31. Kirkpatrick, F. W., Jr., and E. F. Smythe. History and Possible Future of Multiple Reuse of Sewage Effluent at Odessa, Texas Industrial Complex. Chemical Engineering Progress Symposium Series. 63(78):201-209, 1967.

32. Kluth, H. W. Evolution of a Steel Plant Water Supply. Bethlehem Steel Corp. June 1966.

33. Ko, S. C., and L. Duckstein. Collective Utility of Exchanging Treated Sewage Effluent for Irrigation and Mining Water. Hydrology and Water Resources in Arizona and the Southwest. 2:221-234, 1972.

34. Ladd, Kenneth, and S. L. Terry. City Waste Water Reused for Power Plant Cooling and Boiler Makeup. Lubbock, Texas, Southwestern Public Service Co.

35. Leclerc, E. H. T. H. Considerations on Reuse of Water in Certain Industries. Chemical Engineering Progress Symposium Series. 63(78):66-73, 1967.

36. Mayes, W. W., and W. E. Gibson. Successes and Failures in Water Reuse at Cosden Oil and Chemical Co., Big Spring, Texas. Chemical Engineering Progress Symposium Series. 63(78):167-200, 1967.

37. McCormick, E. B., and O. E. Wetzel, Jr. Water Supply from Sewage Effluent. Petroleum Refiner. 33(11): 165-167, 1954.

38. McCoy, J. W. Chemical Analysis of Industrial Water. New York, Chemical Publishing Co., 1969.

39. McIlhenny, W. F. Recovery of Additional Water from Industrial Wastewaters. Chemical Engineering Progress Symposium Series. 36:76, 1967.

40. Mendia, L. Municipal Sewage Reuse for Industrial Purposes. (International Conference on Water for Peace. Washington, D.C. 1967.).

41. National Industrial Pollution Control Council. Waste-Water Reclamation. NIPCC Subcouncil Report. March 1971.

42. Nichols, M. C. Industrial Use of Reclaimed Sewage Water at Amarillo. Journal, American Water Works Association. 47(1):29-33, 1955.

43. Osborn, D. W. Factors Affecting the Use of Purified Sewage Effluents for Cooling Purposes, Johannesburg Municipality (South Africa). Water Pollution Control. 69(4):456.

44. Petrasek, A. C., Jr., S. E. Esmond, and H. W. Wolfe. Municipal Wastewater Qualities and Industrial Requirements. (Paper presented at Complete Water Reuse Meeting. American Institute of Chemical Engineers. Washington, D.C. April 1973.).

45. Pilot Demonstration Project for Industrial Reuse of Renovated Municipal Wastewater. Environmental Protection Agency, Washington, D.C., 1973.

46. Powell, S. T. Adaptation of Treated Sewage for Industrial Use. (Paper presented at the Meeting of American Chemical Society. April 9, 1956.).

47. Powell, S. T. Some Aspects of Requirements for the Quality of Water for Industrial Uses. Sewage Works Journal. 20(36), 1948.

48. Power Plant to Run on Treated Sewage. Power Engineering. 75:54, 1971.

49. Purified Sewage Will Provide Water Supply at the Jurong Industrial Estate, Singapore. Water and Wastes Engineering. 69:208-209, 1965.

50. Renovated Wastewater for Industry? American City. 86(6):118, 1971.

51. Reuse of Sewage Plant Effluent. Industrial Water Engineering. 6(8):32, 1968.

52. Ridge, Richard. The Impact of Public Water Utility Pricing Policy on Industrial Demand and Reuse, Philadelphia General Electric Company. Technical Information Series. November 1972.

53. Scherer, C. H. Fifteen Years Experience with the Reclamation and Industrial Reuse of Amarillo's City Wastewater. (Presented at American Water Works Association Annual Conference).

54. Scherer, C. H. Industrial Reuse of Sewage Plant Effluent. State of Texas Manual for Sewage Plant Operators, 3rd ed. Chapter 23, 1964.

55. Scherer, C. H., and S. L. Terry. Reclamation and Industrial Reuse of Amarillo's Wastewater. Journal of the American Water Works Association. 63(3):159-164, 1971.

56. SCS Engineers. The Role of Desalting in Providing High Quality Water for Industrial Use. Office of Saline Water, Washington, D.C., 1972.

57. Shannon, E. S., and A. Maass. Michigan-Industry Reuse of Treated Waste. Journal of the American Water Works Association. 63(3):154, 1971.

58. Stander, G. J., and J. W. Funke. South Africa Reclaims Effluents as Industrial Water Supply. Water and Wastes Engineering. 6:20, 1969.

59. Steel Mill's Use of Clarified Water Cuts Stream Pollution. Water and Sewage Works. 115:489, 1968.

60. Stone, R. V., H. B. Gotaas, and V. W. Bacon. Economic and Technical Status of Water Reclamation from Sewage and Industrial Wastes. Journal of the American Water Works Association. 44:503-517, 1952.

61. Sullivan, T. F. Sewage Effluent Used for Industrial Water. Journal of the Sanitary Engineering Division, ASCE. (SA 3), 1958.

62. Survey of Renovated Municipal Wastewater Use by Industry. Bechtel Corporation, 1971.

63. Using Effluents as Coolants. Compost Science. 5:31, 1964.

64. Veatch, N. T. Industrial Uses for Reclaimed Sewage Effluents. Sewage Works Journal. 20(3), 1948.

65. Water Requirements of the Petroleum Refinery Industry. U.S. Geological Survey Water Supply Paper 1330-G, 1963.

66. Water Reuse in Industry. Journal Water Pollution Control Federation. 42:237, 1970.

67. Weddle, C. L., and H. N. Masr. Industrial Use of Renovated Municipal Wastewater. Transactions of the ASME, Journal of Engineering for Industry. Paper No. 72-PID-6.

68. Williamson, J. S., and L. Hirsch. Treatment and Reuse of Industrial Wastewater. Water and Sewage Works. 116(IW 24-26), 1969.

69. Wolman, A. Industrial Water Supply from Processed Sewage Treatment Plant Effluent at Baltimore, Md. Sewage Works Journal. 20:15, 1948.

70. Wolters, N. Water Reuse in West German Industry. Chemical Engineering Progress Symposium Series. 63(78):41-45, 1967.

71. Woodruff, E., and H. B. Lammers. Steam Plant Operation. New York, McGraw-Hill, 1967.

72. Zanker, A. Utilization of Treated Wastewater as Cooling Water. Water and Sewage Works. 118:188-189, 1971.

IRRIGATION

1. Bernstein, Leon. Quantitative Assessment of Irrigation Water Quality. Water Quality Criteria. American Society for Testing and Materials. (First National Meeting on Water Quality Criteria. Philadelphia. 1966).

2. Bishop, A. B., and D. W. Hendricks. Analysis of Water Reuse Alternatives in an Integrated Urban and Agricultural Area. Logan, Utah State University, College of Engineering, Utah Water Research Laboratory, Sept. 1971.

3. Bradakis, H. L. Joint Municipal Industry Spray Irrigation Project. Industrial Water and Wastes. 6(4):117-120, 1961.

4. Caspi, B., Y. Zohar, and C. Saliternik. Water Reuse in Israel. Chemical Engineering Progress Symposium Series. 63(78):54-65, 1967.

5. Chaiken, Eugene I., S. Poloncsik, and C. D. Wilson. Muskegon Sprays Sewage Effluents on Land. Civil Engineering, ASCE. 43(5):49-53, 1973.

6. Clark, Colin. The Economics of Irrigation. Oxford, Pergamon Press, 1967.

7. Cluff, C. B., K. J. DeCook, and W. G. Matlock. Technical and Institutional Aspects of Sewage Effluent-Irrigation Water Exchange, Tucson Region. Water Resources Bulletin. 7(4):726-739, Aug. 1971.

8. Cluff, C. B., K. J. DeCook, and W. G. Matlock. Technical, Economic, and Legal Aspects Involved in the Exchange of Sewage Effluent for Irrigation Water for Municipal Use--Case Study, City of Tucson. Tucson, University of Arizona, Dec. 1972.

9. Coe, Jack J., and F. B. Laverty. Wastewater Reclamation in Southern California. Journal of the Irrigation and Drainage Division, ASCE. 98 (IR3 Proc. Paper 9178):419-432, Sept. 1972.

10. Cofer, J. R. Orange County Water District's Water Factory 21. Journal of the Irrigation and Drainage Division, ASCE. 98(IR 4):553-567, Dec. 1972.

11. Corey, J. C., D. R. Nielsen, and D. Kirkham. Miscible Displacement of Nitrate Through Soil Columns. Soil Sci. Soc. Amer. Proc. 31:497-501, 1967.

12. Day, A. D. City Sewage for Irrigation and Plant Nutrients. Crops and Soils. pp. 7-9, 1962.

13. Day, A. D., et al. Effects of Treatment Plant Effluent on Soil Properties. Journal, Water Pollution Control Federation. p. 372, March 1972.

14. Day, A. D., J. L. Stroehlein, and T. C. Tucker. Effects of Treatment Plant Effluent on Soil Properties. Journal, Water Pollution Control Federation, Part 1. March 1972.

15. Doneen, L. D., ed. Proceedings of Conference on the Quality of Water for Irrigation. Davis, California. Jan. 21-22, 1958.

16. Dunlop, S. G., and W. L. Wang. Studies on the Use of Sewage Effluent for Irrigation of Truck Crops. Journal of Milk and Food Technology. 24:44-47, 1961.

17. Dutt, G. R., and T. W. McCreary. The Quality of Arizona's Domestic, Agricultural, and Industrial Waters. University of Arizona Agricultural Experimental Station Report 256. 1970.

18. Eastman, P. W. Municipal Wastewater Reuse for Irrigation. Journal of Irrigation and Drainage Division, ASCE. 93(IR 3):25-31; (IR 1):167-168, 1968.

19. Engineering Feasibility Demonstration Study for Muskegon County, Michigan Wastewater Treatment-Irrigation System. Muskegon, Michigan. Muskegon County Board and Department of Public Works, 1970.

20. Evaluation of Land Application Systems. Environmental Protection Agency, Office of Water Programs Operations, Washington, D.C. Technical Bulletin, EPA-430/9-75-001. March 1975.

21. Feinmesser, A. Survey of Wastewater Utilization. Department of Supervision Over Agricultural Water, National Water Commission, 1963.

22. Garthe, E. C., and W. C. Gilbert. Water Reuse at Grand Canyon. Journal, Water Pollution Control Federation. 40(9):1582-1585, 1968.

23. Gray, J. F. Irrigation Processes Using Reclaimed Water of Effluent Described. West Texas Today. 45:18-19, 23, 1965.

24. Guymon, B. E. Sewage Salinity Prevents Use of Effluent for Golf Course Irrigation. Wastes Engineering. 28(2):80-83, 1957.

25. Hansen, William F. Some Research Findings on the Bennett Springs Sewage Irrigation Project. (Unpublished Data.) University of Missouri, 1972.

26. Heukelekian, H. Utilization of Sewage for Crop Irrigation in Israel. Sewage and Industrial Wastes. 29:868-874, 1957.

27. Hillinger, Charles. Farmer Finds Boon in Drip Irrigation. Los Angeles Times. Nov. 11, 1972.

28. Hunt, Patrick. Microbiological Responses to the Land Disposal of Secondary-Treated Municipal-Industrial Wastewater. In: Wastewater Management by Disposal on Land. U.S. Army, Corps of Engineers. Special Report 171. 1972.

29. Hyde, C. G. The Beautification and Irrigation of Golden Gate Park with Activated Sludge Effluent. Sewage Works Journal. 9:929-941, 1937.

30. Irrigate with the Wastewater. American City. p. 24, March 1972.

31. Israel's Wastewater Reclamation Scheme. World Construction. 22(8):37-39, 1969.

32. Israel Turns to Sewage for Water. Engineering News-Record. p. 42, 1969.

33. Israel, Ministry of Health. Special Conditions for Use of Wastewater in Agriculture. 1965.

34. Kardos, L. T. Crop Response to Sewage Effluent, Symposium on Municipal Sewage Effluent for Irrigation. Louisiana Polytechnic Institute, 1968.

35. Ko, S. C., and L. Duckstein. Collective Utility of Exchanging Treated Sewage Effluent for Irrigation and Mining Water. Hydrology and Water Resources in Arizona and the Southwest. 2:221-234, 1972.

36. Kruez, C. A. Hygienic Evaluation of the Agricultural Utilization of Sewage. Gesundheitsingenieur. 76:206-211, 1955.

37. Lau, L. Stephen. Water Recycling of Sewage Effluent by Irrigation: A Field Study on Oahu. First Progress Report. Honolulu, University of Hawaii, Water Resources Research Center, Nov. 1972.

38. Law, J. P., Jr. Agricultural Utilization of Sewage Effluent and Sludge. Environmental Protection Agency, Washington, D.C.

39. Litton, B. R., Jr. Landscape and Esthetic Quality. In: America's Changing Environment, Revelle, R. and H. H. Landsberg (eds.). Boston, Houghton Mifflin, 1970.

40. McQueen, F. Sewage Treatment for Obtaining Park Irrigating Water. Public Works. 64:16-17, 1933.

41. Merz, R. C. Waste Water Reclamation for Golf Course Irrigation. Journal of the Sanitary Engineering Division, ASCE. 85(SA 6):79-85, 1959.

42. Moore, C. V., and T. R. Hedges. Economics of On-Farm Irrigation Availability and Costs and Related Farm Adjustments: Farm Size Relation to Resource Use, Earnings, and Adjustments on the San Joaquin Eastside. California Agricultural Experimental Station, Berkeley. Research Report 263. 1963.

43. Neveux, M. M., O. Jaag, and J. Kieling. Agricultural Utilization of Sewage Effluent. Techniques et Sciences Municipales. 54:425-432, 1959.

44. Orcutt, R. D. An Engineering-Economic Analysis of Systems Utilizing Aquifer Storage for the Irrigation of Parks and Golf Courses with Reclaimed Wastewater. University of Nevada Desert Research Institute, Center for Water Resources Research. Technical Report Series H-W. Publication No. 5. 1967.

45. Pennypacker, S. P., W. E. Sopper, and L. T. Kardos. Renovation of Wastewater Effluent by Irrigation of Forest Land. Journal of Water Pollution Control Federation. 39(2):285, 1967.

46. Schouten, Maria. Land Disposal of Municipal Waste Stabilization Pond Effluent. Unpublished data. Ministry of the Environment, Ontario, Canada, 1971.

47. Schouten, Maria. Smithville Spray Irrigation Study Progress Report. Unpublished data. Ministry of the Environment, Ontario, Canada, 1972.

48. Sepp, Endel. Disposal of Domestic Waste Water by Hillside Sprays. Journal of the Environmental Engineering Division, ASCE. (EE 2):109-121, 1973.

49. Skulte, B. P. Irrigation with Sewage Sewage and Industrial Wastes. 28:36-43, 1956.

50. Sloan, G. Waste Water Reclamation for Golf Course Irrigation. Journal of the Sanitary Engineering Division, ASCE. 86(SA 3):167, 1960.

51. Sopper, W. E. Effects of Irrigation of Municipal Sewage Effluent on Spoil Banks. Pennsylvania State University, December 1971.

52. Sopper, W. E. Renovation of Municipal Sewage Effluent for Groundwater Recharge Through Forest Irrigation. International Conference on Water for Peace, Washington, D.C. Paper No. 571. 1967.

53. Sopper, W. E., and L. T. Kardos. Sewage Effluent and Sludge Successfully Revegetate Strip Mine Spoil Banks. Science in Agriculture. 18(3):10-11, 1971.

54. Sowing with Sewage. Mechanical Engineering. 92(7):48, 1970.

55. Sparks, J. T. Sewage Irrigation in the Mitchell Lake Area, Texas. Sewage and Industrial Wastes. 25:233-234, 1953.

56. Stevens, R. M. (ed.). Green Land--Clean Streams: The Beneficial Use of Wastewater Through Land Treatment. Philadelphia, Center for the Study of Federalism, Temple University, 1972.

57. Storm, D. R. Land Disposal, One Answer. Water and Wastes Engineering. 8:46-47, 1971.

58. Sullivan, Richard H., M. M. Cohn, and S. S. Baxter. Survey of Facilities Using Land Application of Wastewater. Environmental Protection Agency, Washington, D.C., July 1973.

59. Tofflemire, T. J., and F. E. Van Alstyne. Literature Review - Land Disposal of Wastewater for 1973. New York State Department of Environmental Conservation, Albany, N.Y. Technical Paper No. 33. Feb. 1974.

60. Viraraghavan, T. Sewage Treatment with Special Reference to Use on Land for Irrigation. Institution of Engineers (India). 50(2):25-28, 1969.

61. Wastewater Treatment and Reuse by Land Application, Volumes I and II. Environmental Protection Agency, Washington, D.C., 1973.

62. Wells, W. N. Irrigation as a Sewage Re-Use Application. Public Works. 92:116, 1961.

63. Wells, W. N. Sewage Plant Effluent for Irrigation. Compost Science. 4:19, 1963.

64. Wierzbicki, J. Augmenting Water Supply Through Agricultural Utilization of Municipal Sewage. Gaz, Wod i Technika Sanitarna. 31:17, 1957.

65. Williams, Roy E., and D. D. Eier. The Feasibility of Refuse of Chlorinated Sewage Effluent for Fertilization and Irrigation in Idaho. Moscow, University of Idaho Graduate School, 1971.

66. Williams, Roy E., D. D. Eier, and A. T. Wallace. Feasibility of Re-Use of Treated Wastewater for Irrigation, Fertilization and Ground-water Recharge in Idaho. Idaho Bureau of Mines and Geology, Moscow, 1969.

67. Wilson, C. W., and R. P. Cantrell. A Study of the Technical and Economic Feasibility of Using Sewage Effluent for Irrigation in Lincoln Parish, La. 1969.

68. Younger, V. B., and W. D. Kesner. Ecological and Physiological Implications of Greenbelt Irrigation. Riverside, University of California, July 1, 1970.

69. Zillman. Organization of the Application of Sewage as Artificial Rain in Wolfsburg. Stadtehygiene. 7:53, 1956.

POTABLE WATER

1. Besik, F. Reclamation of Potable Water from Domestic Sewage. Water Pollution Control (Canada). 109(4):35; (5):46; (6):38, 1971.

2. Besik, F. Wastewater Reclamation in a Closed System. Water and Sewage Works. pp. 213-219, 1971.

3. Bowen, D. H. M. Effluents are Tasting Better and Better. Environmental Science and Technology. 5(2), 1971.

4. Chemical Process Purifies Wastewater, Makes it Drinkable. Product Engineering. 40(15), 1965.

5. Clayton, A. J., and P. J. Pybus. Windhoek Reclaiming Sewage for Drinking Water. Civil Engineering-ASCE. pp. 103-106, Sept. 1972.

6. Connell, C. H., and E. J. M. Berg. Reclaiming Municipal Waste Water for Industrial and Domestic Re-Use. Southwest Water Works Journal. 41:17-19, 1960.

7. The Feasibility of Wastewater Renovation for Domestic Use. Toups Engineering, Inc. Santa Ana, California. 1966.

8. Gardner, B. D., and S. H. Schick. Factors Affecting Consumption of Urban Household Water in Northern Utah. Agricultural Experiment Station Bulletin No. 449, Nov. 1964.

9. Garthe, E. C., and W. C. Gilbert. Water Reuse at Grand Canyon. Journal, Water Pollution Control Federation. 40(9):1582-1585, 1968.

10. Gruenwald, A. Drinking Water from Sewage? American City. 82:3, 1967.

11. Hanson, R., and H. E. Hudson, Jr. Trends in Residential Water Use. Journal of the American Water Works Association. pp. 1347-1358, Nov. 1956.

12. Karassik, I. J., and J. F. Sebald. Pasterilized Water: Potable Supplies from Waste Water Effluents. Public Works. 94:131-133, 1963.

13. Linaweaver, F. P., Jr., J. C. Geyer, and J. B. Wolff. A Study of Residential Water Use. Department of Housing and Urban Development, Technical Studies Program of the Federal Housing Administration, Washington, D.C., Feb. 1967.

14. Linaweaver, F. P., Jr., J. C. Geyer, and J. B. Wolff. Final and Summary Report on the Residential Water Use Project. Baltimore, Johns Hopkins University, Department of Environmental Engineering Science, July 1966.

15. Metzler, D. F. The Reuse of Treated Wastewater for Domestic Purposes. Public Works. p. 117, 1958.

16. Metzler, D. F., et al. Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas. Journal, American Water Works Association. 50(8):1021, 1958.

17. Neale, J. H. Washing Water. Science and Technology. pp. 52-57, June 1969.

18. Nupen, E. M. Virus Studies on the Windhoek Wastewater Reclamation Plant South-West Africa. Water Research. 4(10), 1970.

19. On the Use of Reclaimed Wastewaters as a Public Water Supply Source. Journal of the American Water Works Association. 63:490, 1971.

20. Stander, G. J. Reclamation of Potable Water from Sewage. Water Pollution Control (London). 68:5513-5522, 1969.

21. Stander, G. J., and J. W. Funke. Direct Cycle Water Reuse Provides Drinking Water Supply in South Africa. Water and Wastes Engineering. 6(5):66, 1969.

22. Stander, G. J., and L. R. J. Van Vuuren. The Reclamation of Potable Water from Wastewater. Journal of the Water Pollution Control Federation. p. 355, March 1969.

23. Weinstein, R. H. Water Recycling for Domestic Use. Astronautics and Aeronautics. p. 44, March 1972.

24. Wolf, H. W., and S. E. Esmond. Water Quality for Potable Refuse of Wastewater. Unpublished data. Dallas, Texas, 1972.

RECREATIONAL REUSE

1. Apollo County Park, Wastewater Reclamation Project for the Antelope Valley Area. Los Angeles County, Los Angeles Department of County Engineers, 1971.

2. Bauer, J. H. Air Force Academy Sewage Treatment Plant Designed for Effluent Re-Use. Public Works. 92(6):120-122, 1961.

3. Brown, W. G. An Economic Evaluation of the Oregon Salmon and Steelhead Sport Fishery. Technical Bulletin No. 68. Corvallis, Oregon State Agricultural Experimental Station, 1964.

4. Brungs, William A. Chronic Effects of Constant Elevated Temperature on the Fathead Minnow. Transactions, American Fish Society. 100(4):659-664, 1971.

5. Cesario, F. J., and J. L. Knetsch. Time Bias in Recreation Benefit Estimates. Water Resources Research. 6(3):700-704, 1970.

6. Clawson, M., and J. L. Knetsch. Economics of Outdoor Recreation. Baltimore, Johns Hopkins Press for Resources for the Future, 1966.

7. Culp, R. L., and H. E. Moyer. Wastewater Reclamation and Export at South Tahoe. Civil Engineer (New York). 39(6):38-42, 1969.

8. Culp, R. L., J. C. Wilson, and D. R. Evans. Advanced Wastewater Treatment as Practiced at South Tahoe. Environmental Protection Agency, Water Quality Office, Washington, D.C., 1971.

9. Davidson, P., G. F. Adams, and J. Seneca. The Social Value of Water Recreational Facilities Resulting from an Improvement in Water Quality: The Delaware Estuary. (In Water Research.) Baltimore, The Johns Hopkins Press, 1966.

10. Dobie, J., O. L. Meeheon, S. F. Snieszko, and G. N. Washburn. Circular No. 35. U.S. Fish and Wildlife Service, 1956.

11. Dornbush, J. N., and J. R. Andersen. Ducks on the Wastewater Pond. Water and Sewage Works. 3(6):271-276, 1964.

12. Fish Raised in Wastewater Lagoons. American City. p. 148, June 1972.

13. Grubb, H. W., and J. T. Goodwin. Economic Evaluation of Water-Oriented Recreation in the Preliminary Texas Water Plan. Rep. 84, Texas Water Development Board, Austin, 1968.

14. Hallock, R. J., and C. D. Ziebell. Feasibility of a Sport Fishery in Tertiary Treated Wastewater. Journal, Water Pollution Control Federation. 42:1656-1665, 1970.

15. Houser, E. W. Santee Project Continues to Show the Way. Water and Wastes Engineering. 7(5):40-44, 1970.

16. Huggins, T. G. Production of Channel Catfish (Ictalurus punctatus) in Tertiary Treatment Ponds. (Unpublished Manuscript Thesis.) Iowa State University, 1969.

17. Kalter, R. J., and L. E. Gosse. Outdoor Recreation in New York State: Projections of Demand, Economic Value, and Pricing Effects. Cornell Univ. Agr. Exp. Station Spec. Series, Vol. 5. Ithaca, Cornell University, 1969.

18. Konefes, J. L., and R. W. Backman. Growth of Fathead Minnow (Pimephales promelas) in Tertiary Treatment Ponds. Iowa Academy of Science. 77:104-111, 1970.

19. Moyer, H. E. South Lake Tahoe Water Reclamation Project. Public Works. 99(12):87-94, 1968.

20. Wakeman, B. New Lake at South Lake Tahoe, California. Water and Sewage Works. 115:348-349, 1968.

21. Winn, Walter T., D. M. Wells, and R. M. Sweazy. Recreational Reuse of Municipal Wastewater. Lubbock, Texas Tech University, Water Resources Center, July 1973.

APPENDICES

A - Inventory of Wastewater Reuse Locations in the United States

B - Minimum Water Quality Requirements of Selected Various Water Users

C - Values of the ENR Construction Cost Index 1966-1974

D.- Cost Curves for Estimating Capital and Operating and Maintenance Expenditures for Water Resource Facilities

E - Seven Percent Compound Interest Factors

APPENDIX A

INVENTORY OF WASTEWATER REUSE LOCATIONS IN THE UNITED STATES

TABLE A-1 Effluent Used for Industrial Purposes

TABLE A-2 Effluent Used for Irrigation Purposes

TABLE A-3 Effluent Used for Groundwater Recharge

TABLE A-4 Effluent Used for Fish Propagation Purposes and Recreation

TABLE A-5 Effluent Used for Research and Development Purposes

Note: Wastewater reuse facilities are tabulated in alphabetical order according to state name on each of Tables A-1 through A-5.

TABLE A-1

INVENTORY OF WASTEWATER REUSE LOCATIONS IN THE UNITED STATES

EFFLUENT USED FOR INDUSTRIAL PURPOSES

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg	Comments
Bagdad Copper Corp.	Bagdad, AZ	0.2	0	
Phelps Dodge Corp.	Morenci, AZ	0.6	0	
Burbank, CA	Burbank, CA	2.0	43.00	End use quality desires low TDS, SS, PO_4^-, NO_3^-, organics. User treatment: shock chlorination, pH adjust, corrosion inhibitor
Colorado Springs, CO	Colorado Springs, CO	21	300	User treatment: cold lime filt., carbon adsorption.
Baltimore, MD	Baltimore, MD	120	1.33	
Las Vegas, NV	Las Vegas, NV	27	20	User treatment: cold lime clarif.
Las Vegas, NV Clark Co. San. Dist.	Las Vegas, NV	12.5	30	User treatment: cold lime clarif.

TABLE A-1 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg	Comments
Midland, MI	Midland, MI	6.0	3.33	
Enid, OK	Enid, OK	2.0	7.00	
Amarillo, TX	Amarillo, TX	10	80/90	Multiple users, graduated charges. User treatment: cold lime, alum floc., clar., soft.
Big Spring, TX	Big Spring, TX	0.5	79	Graduated charge.
Denton, TX	Denton, TX	1.5	80	User treatment: shock chlorination, pH adjustment.
Lubbock, TX	Lubbock, TX	6.5	119	User treatment: cold lime, pH adjustment, anth-filt, reverse osmosis, zeolite
Odessa, TX	Odessa, TX	5.5	125	User pay municipal treatment costs.

TABLE A-2

INVENTORY OF WASTEWATER REUSE LOCATIONS IN THE UNITED STATES

EFFLUENT USED FOR IRRIGATION

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Casa Grande, AZ	Casa Grande, AZ	1.0	7
Flagstaff, AZ	Flagstaff, AZ	1.0	36
Arizona State Prison	Florence, AZ	0.7	0
Ft. Huachuca Mil. Res.	Ft. Huachuca, AZ	1.0	0
Grand Canyon, AZ	Grand Canyon, AZ	0.03	1,000
Kearny, AZ	Kearny, AZ	0.5	0
Lake Havasu, AZ	Lake Havasu, AZ	0.6	0
Mesa, AZ	Mesa, AZ	4.3	3.00
23rd Avenue Plant	Phoenix, AZ	28.0	0
91st Avenue Plant	Phoenix, AZ	60.0	4.30

0 $/mg - No charge to users
-- $/mg - Data not available

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Prescott, AZ	Prescott, AZ	0.5	0
BIA, Shonto School Board	Shonto, AZ	0.1	0
Tolleson, AZ	Tolleson, AZ	1.1	0
Tuscon, AZ	Tuscon, AZ	14.0	0
Wilcox, AZ	Wilcox, AZ	0.2	0
Winslow, AZ	Winslow, AZ	0.5	0
Armona, CA	Armona, CA	0.3	0
Arvin, CA	Arvin, CA	0.5	User charges: 25% of farm income.
Avenal, CA	Avenal,CA	0.5	User charges: 20% of farm income.
Plant #1	Bakersfield, CA	3.6	0

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Plant #2	Bakersfield, CA	8.5	0
Mt. Vernon Co. San. Dist.	Bakersfield, CA	3.8	0
No. of River San. Dist. #1	Bakersfield, CA	2.3	0
Barstow (USMC)	Barstow, CA	0.14	--
Brentwood	Brentwood, CA	0.14	--
Buttonwillow	Buttonwillow, CA	0.18	--
CA Conservation Center	CA	0.04	--
Las Virgenes MWD	Calabasas, CA	3.0	$5
Callan, CA	Callan, CA	0.27	--
Camarillo, CA	Camarillo, CA	2.3	0
Camarillo St. Hospital	Camarillo, CA	0.3	0

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Camp Pendleton	CA	0.82	--
Carmel San. Dist.	Carmel, CA	0.14	--
Chester, CA	Chester, CA	0.16	--
Naval Weapons Center	China Lake, CA	0.7	0
Chino, CA	Chino, CA	2.4	0
Chowchilla, CA	Chowchilla, CA	0.68	--
California Institute for Men	Chino, CA	0.5	0
Coachella San. Dist.	Coachella, CA	0.2	0
Coit Ranch, Inc.	CA	0.03	--
Colton, CA	Colton, CA	1.9	--
Corcoran, CA	Corcoran, CA	0.68	--
Corning, CA	Corning, CA	0.2	0
Cutler PUD	Cutler, CA	0.3	User charges: 25% of farm income.

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Delano, CA	Delano, CA	2.7	0
Dinuba, CA	Dinuba, CA	2.4	--
Earlimart PUD	Earlimart, CA	0.3	0
Elsinore, CA	Elsinore, CA	0.30	--
El Toro Marine Base (USMC)	El Toro, CA	0.96	--
Encinitas San. Dist.	Encinitas, CA	0.47	--
Exeter, CA	Exeter, CA	0.7	$4.20
Fallbrook San. Dist.	Fallbrook, CA	0.06	0
Fontana, CA	Fontana, CA	2.3	--
Fowler, CA	Fowler, CA	0.23	--
Plant #1	Fresno, CA	3.9	0
Plant #2	Fresno, CA	1.8	0
George AFB, CA	George AFB, CA	0.5	0
Golden Gate Park	San Francisco, CA	0.63	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Guadalupe, CA	Guadalupe, CA	0.5	0
Gustine, CA	Gustine, CA	2.0	0
Hanford, CA	Hanford, CA	2.0	0
Hemet, CA	Hemet, CA	1.0	$18
Huron, CA	Huron, CA	0.27	--
Valley San. Dist.	Indio, CA	0.3	0
Irvine Ranch W.D.	Irvine, CA	2.8	$120
Ivanhoe PUD	Ivanhoe, CA	0.3	0
Kerman, CA	Kerman, CA	0.3	--
L.A. County San. Dist.	LaCanada, CA	0.16	0
Rossmoor Sanitation, Inc.	Laguna Hills, CA	1.4	--
Moulton Niguel W.D.	Laguna Niguel, CA	0.4	--
Lakeport, CA	Lakeport, CA	0.26	--
Lamont, CA	Lamont, CA	0.08	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Lemoore, CA	Lemoore, CA	0.36	--
Leucadia Co. W.D.	Leucadia, CA	0.5	0
Lindsay, CA	Lindsay, CA	0.30	--
Livermore, CA	Livermore, CA	4.2	0
Lodi, CA	Lodi, CA	3.7	0
Log Cabin Ranch School	CA	0.01	--
Loma Linda University	Loma Linda, CA	0.11	--
L.A. County San. Dist. LaCanada Plant	Los Angeles, CA	0.1	0
L.A. County San. Dist. Lancaster Plant	Los Angeles, CA	0.5	0
L.A. County San. Dist. Palmdale Plant	Los Angeles, CA	0.7	$5
L.A. County San. Dist. Pamona Plant	Los Angeles, CA	0.7	$22
Madera, CA	Madera, CA	2.38	--
Manteca, CA	Manteca, CA	1.37	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
March Plant	March AFB, CA	0.4	$1.00 per year user charge
West March Plant	March AFB, CA	0.3	$1.00 per year user charge
McFarland, CA	McFarland, CA	0.3	0
Meadowood, CA	Meadowood, CA	0.01	--
Mendolino State Hosp.	CA	0.05	--
Mojave PUD	Mojave, CA	0.3	$1.00 per year charge
Mount Vernon San. Dist.	Bakersfield, CA	3.56	0
Murphy's San. Dist.	CA	0.05	--
North of River San. Dist.	Bakersfield, CA	2.33	0
Oceanside, CA	Oceanside, CA	0.6	0
Ontario-Upland	Ontario, CA	0.96	--
Orange Cove, CA	Orange Cove, CA	0.4	0

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Pacific Union College	CA	0.13	--
Palmdale, CA	Palmdale, CA	1.10	--
Palm Springs, CA	Palm Springs, CA	1.0	0
Patterson, CA	Patterson, CA	.01	--
Pinedale, CA	Pinedale, CA	0.75	--
Pixley, CA	Pixley, CA	--	--
Pleasanton, CA	Pleasanton, CA	1.3	0
Pomerado Co., CA Water Dist.	Poway, CA	0.05	0
Rainbow Municipal Water Dist.	Fallbrook, CA	0.02	0
Rancho Bernardo	San Diego, CA	0.41	0
Reedley, CA	Reedley, CA	1.1	--
Ridgecrest Co. San. Dist.	Ridgecrest, CA	0.58	--
Ripon, CA	Ripon, CA	0.3	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Riverbank, CA	Riverbank, CA	0.4	--
Riverdale, CA	Riverdale, CA	0.14	--
Riverside, CA	Riverside, CA	17.5	--
Rossmoor Sanitation, Inc.	Laguna Niguel, CA	1.10	--
San Bernardino Co. Special Dist. Div. Co.	San Bernardino, CA	0.5	--
San Bernardino, CA	San Bernardino, CA	3.0	$15
San Fran. Co. Jail #2	San Bruno, CA	0.1	0
San Clemente, CA	San Clemente, CA	2.0	User charge: 1/2 potable water cost
Santee County Water Dist.	San Diego, CA	3.2	--
San Juan Bautista, CA	San Juan Bautista, CA	2.8	--
McQueen STP	San Francisco, CA	0.9	0
San Luis Obispo, CA	San Luis Obispo, CA	--	0
San Pasqual Academy	CA	0.01	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Sanger, CA	Sanger, CA	0.93	--
Laguna Co. San. Dist.	Santa Maria, CA	1.3	0
Santa Paula, CA	Santa Paula, CA	1.5	--
Santa Rosa, CA	Santa Rosa, CA	0.2	--
Santee, CA	Santee, CA	1.0	$150
Sebastopol, CA	Sebastopol, CA	0.14	0
Shafter, CA	Shafter, CA	1.0	0
Shastina San. Dist.	CA	0.14	--
Soledad, CA	Soledad, CA	0.4	--
Solvang, CA	Solvang, CA	0.08	--
South Lake Tahoe, CA	South Lake Tahoe, CA	2.7	0
Stratford. CA	Stratford, CA	0.003	--
Strathmore, PUD	Strathmore, CA	0.2	0
Susanville San. Dist.	Susanville, CA	0.2	0
Taft, CA	Taft, CA	1.0	User charge flat fee

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Tehachapi, CA	Tehachapi, CA	0.4	0
Terra Bella Sewer Main Dist, CA	CA	--	--
Thousand Oaks, CA	Thousand Oaks, CA	0.1	$220
Tipton, CA	Tipton, CA	--	--
Tulare, CA	Tulare, CA	3.8	$19
Tuolumne, CA	Tuolumne, CA	0.135	--
U.S. Marine Corps.	Twenty-Nine Palms,CA	0.5	0
Valley Center MWD	Valley Center, CA	0.01	0
Ventura, CA	Ventura, CA	0.3	0
Visalia, CA	Visalia, CA	5.1	0
Warner Springs Resort Co.	Warner Hot Springs, CA	0.03	--
Wasco PUD	Wasco, CA	0.7	0
Waterford Comm. Serv. Dist., CA	Waterford, CA	0.3	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Weed, CA	Weed, CA	0.2	0
Westwood Comm. Serv. Dist., CA	CA	0.86	--
Wheatland Dept. of Public Works, CA	Wheatland, CA	0.15	--
Winton San. Dist.	CA	0.41	--
Woodlake, CA	Woodlake, CA	0.16	--
Woodland, CA	Woodland, CA	6.0	0
Aurora, CO	Aurora, CO	0.4	$240
Colorado Springs, CO	Colorado Springs, CO	7.0	$94
U.S. Air Force Academy	Colorado Springs, CO	1.4	0
Fitzsimons Gen. Hospital	Denver, CO	0.5	0
Ft. Carson, CO	Ft. Carson, CO	0.5	0
Cocoa Beach. FL	Cocoa Beach, FL	1.0	0

* Research & Development

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Okaloosa County Water and Sewer Dist.	Elgin Air Force Base, FL	1.0	0
St. Petersburg, FL	St. Petersburg, FL	0.2	--
Tallahassee, FL	Talahassee, FL	2.0	0
Walt Disney World, FL	Walt Disney World, FL	1.5	--
Western Farmers Assoc.	Aberdeen, ID	0.5	--
Boise, ID	Boise, ID	0.1	0
Green Giant Company	Buhl, ID	1.0	--
Celotex Corporation	Largo, IN	0.18	--
Commercial Solvents	Terre Haute, IN	0.07	--
Sublette, KS	Sublette, KS	0.13	--
Chesapeake Foods	Cordova, MD	0.55	--
St. Charles Utilities, Inc.	St. Charles, MD	0.5	--
Belding, MI	Belding, MI	0.05	0
Cassopolis, MI	Cassopolis, MI	0.13	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
East Jordan, MI	East Jordan, MI	0.25	--
Gerber Products Company	Fremont, MI	0.8	--
Sewage Disposal Auth.	Harbor Springs Area-MI	0.5	--
Harrison, MI	Harrison, MI	0.07	--
Celotex Corporation	L'Anse, MI	0.6	--
Middleville, MI	Middleville, MI	0.025	--
Ohawa Co. Rd. Comm, MI	MI	0.008	--
Michigan Milk Producers Association	Ovid, MI	0.25	--
Stokely Van Camp	Fairmont, MN	1.5	--
Green Giant Company	Montgomery, MN	1.2	--
Mo. State Park Board	Jefferson City, MO	0.04	0
Lockwood, MO	Lockwood, MO	0.5	0
Helena, MT	Helena, MT	3.0	--
West Yellowstone, MT	West Yellowstone, MT	0.5	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Grant, NE	Grant, NE	0.171	--
Shelby, NE	Shelby, NE	--	--
Ely, NV	Ely, NV	1.0	0
Las Vegas, NV	Las Vegas, NV	3.8	$20
Clark Co. San. Dist.	Las Vegas, NV	4.3	$30
Winnemucca, NV	Winnemucca, NV	0.4	0
Hunt-Wesson Foods, Inc.	Bridgeton, NJ	3.5	--
Forgate Sanitation, Inc.	Cranbury, NJ	0.5	--
H.J. Heinz Company	Salem, NJ	1.3	--
Alamogordo, NM	Alamogordo, NM	2.5	--
Artesia, NM	Artesia, NM	0.6	Flat rate annual bid
Clovis, NM	Clovis, NM	4.0	User charge: $1000 per yr.
Deming, NM	Deming, NM	1.5	User charge: $1000 per yr.

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Dexeter, NM	Dexeter, NM	1.5	Flat rate
Jal, NM	Jal, NM	0.3	$40 per month flat rate
Lordsburg, NM	Lordsburg, NM	0.3	0
Los Alamos Co. Utilities	Los Alamos, NM	0.2	$120
Lovington, NM	Lovington, NM	0.5	--
Portales, NM	Portales, NM	1.0	--
Raton, NM	Raton, NM	0.5	User charge: $200 per yr.
Roswell, NM	Roswell, NM	3.0	$11
Airport Road Plant	Sante Fe, NM	0.8	--
Siler Road Plant	Sante Fe, NM	2.5	--
Tucumcari, NM	Tucumcari, NM	0.1	0
Dickinson, ND	Dickinson, ND	0.1	0
Boise City, OK	Boise City, OK	.001	--
Duncan, OK	Duncan, OK	0.5	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Frederick, OK	Frederick, OK	0.2	0
Bend, OR	Bend, OR	0.5	--
Unified Sewerage Agency	Forest Grove, OR	2.0	--
Hillsboro, OR	Hillsboro, OR	2.0	0
Milton-Freewater, OR	Milton-Freewater, OR	2.7	--
U.S. Gypsum Company	Pilot Rock, OR	1.2	--
Weyerhaeuser Company	Springfield, OR	0.5	--
Pet Milk Company	Biglerville, PA	0.205	--
Abernathy, TX	Abernathy, TX	0.13	--
Abilene, TX	Abilene, TX	3.2	0
Amarillo, TX	Amarillo, TX	6.3	$80-90
Amherst, TX	Amherst, TX	0.08	--
Anson, TX	Anson, TX	0.19	--
Anton, TX	Anton, TX	0.04	--
Aspermont, TX	Aspermont, TX	0.10	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Benjamine, TX	Benjamine, TX	0.04	--
Bexar County, TX	TX	0.005	--
Big Lake, TX	Big Lake, TX	0.15	--
Blanco, TX	Blanco, TX	0.04	--
Bonham, TX	Bonham, TX	1.4	--
Barger, TX	Barger, TX	0.88	--
Brady, TX	Brady, TX	0.50	--
Brownfield, TX	Brownfield, TX	0.47	--
Burkburnet, TX	Burkburnet, TX	0.65	--
Burnet, TX	Burnet, TX	0.14	--
Castroville, TX	Castroville, TX	0.04	--
Coahoma, TX	Coahoma, TX	0.05	--
Cofulla, TX	Cofulla, TX	0.165	--
Coleman, TX	Coleman, TX	0.3	--
Colorado City, TX	Colorado City, TX	0.51	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Comanche, TX	Comanche, TX	0.4	--
Comfort, TX	Comfort, TX	0.002	--
Crane, TX	Crane, TX	0.31	--
Crockett County, TX	Crockett County, TX	0.001	--
Crosbyton, TX	Crosbyton, TX	0.14	--
Cross Plains, TX	Cross Plains, TX	0.06	--
Crystal City, TX	Crystal City, TX	1.20	--
Dalhart, TX	Dalhart, TX	0.64	--
Del Rio, TX	Del Rio, TX	0.40	--
Denison, TX	Denison, TX	0.15	--
Denver City, TX	Denver City, TX	0.35	--
Devine, TX	Devine, TX	0.08	--
Dimmitt, TX	Dimmitt, TX	0.82	--
Dublin, TX	Dublin, TX	1.0	--
Dumas, TX	Dumas, TX	1.0	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Earth, TX	Earth, TX	0.09	--
Eldorado, TX	Eldorado, TX	0.09	--
El Paso, TX	El Paso, TX	0.45	--
El Sa, TX	El Sa, TX	0.002	--
Fabens, TX	Fabens, TX	0.001	--
Falforias, TX	Falforias, TX	0.35	--
Falls City, TX	Falls City, TX	0.02	--
Farwell, TX	Farwell, TX	0.79	--
Florence, TX	Florence, TX	0.046	--
Floydada, TX	Floydada, TX	0.07	--
Fort Stockton, TX	Fort Stockton, TX	0.90	--
Fredericksburg, TX	Fredericksburg, TX	0.001	--
Freer, TX	Freer, TX	0.16	--
Friona, TX	Friona, TX	0.25	--
Fritch, TX	Fritch, TX	0.40	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Goldthwaite, TX	Goldthwaite, TX	0.06	--
Gorman, TX	Gorman, TX	0.08	--
Graford, TX	Graford, TX	0.02	--
Grand Falls, TX	Grand Falls, TX	0.04	--
Granger, TX	Granger, TX	0.70	--
Hale Center, TX	Hale Center, TX	0.13	--
Happy, TX	Happy, TX	0.07	--
Hart, TX	Hart, TX	0.18	--
Holliday, TX	Holliday, TX	0.13	--
Honahans, TX	Honahans, TX	0.90	--
Hondo, TX	Hondo, TX	0.4	0
Idaldo, TX	Idaldo, TX	0.09	--
Idalou, TX	Idalou, TX	0.2	--
Ingleside, TX	Ingleside, TX	0.001	--
Johnson City, TX	Johnson City, TX	0.04	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Karnes City, TX	Karnes City, TX	0.12	--
Kermit, TX	Kermit, TX	0.83	--
Kerrville, TX	Kerrville, TX	0.001	--
Kilgore, TX	Kilgore, TX	0.005	--
Kingsville, TX	Kingsville, TX	0.81	--
La Coste, TX	La Coste, TX	0.04	--
La Mesa, TX	La Mesa, TX	1.13	--
Lorenlo, TX	Lorenlo, TX	0.08	--
Levelland, TX	Levelland, TX	0.66	--
Littlefield, TX	Littlefield, TX	0.47	--
Llano, TX	Llano, TX	0.28	--
Lubbock, TX	Lubbock, TX	11.4/2.8	$119-IND*
Lyford, TX	Lyford, TX	0.27	--
Lockney, TX	Lockney, TX	0.14	--
McCamey, TX	McCamey, TX	0.23	--

* Industrial

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
McKinley, TX	McKinley, TX	1.5	--
McKinney, TX	McKinney, TX	--	--
McLean, TX	McLean, TX	0.13	--
Marfa, TX	Marfa, TX	0.23	--
Mason, TX	Mason, TX	0.14	--
Meadow, TX	Meadow, TX	0.04	--
Midland, TX	Midland, TX	4.3	0
Miles, TX	Miles, TX	0.02	--
Monahans, TX	Monahans, TX	1.00	--
Morton, TX	Morton, TX	0.24	--
Muleshoe, TX	Muleshoe, TX	0.5	--
Munday, TX	Munday, TX	0.21	--
Nordheim, TX	Nordheim, TX	0.01	--
O'Donnell, TX	O'Donnell, TX	0.07	--
Orange Grove, TX	Orange Grove, TX	0.06	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Paducah, TX	Paducah, TX	0.23	--
Pearsall, TX	Pearsall, TX	0.23	--
Pecas, TX	Pecas, TX	0.33	--
Perryton, TX	Perryton, TX	1.0	--
Petersburg, TX	Petersburg, TX	0.10	--
Plains, TX	Plains, TX	0.09	--
Poteet, TX	Poteet, TX	0.19	--
Premont, TX	Premont, TX	0.20	--
Quitaque, TX	Quitaque, TX	0.04	--
Ralls, TX	Ralls, TX	0.20	--
Rankin, TX	Rankin, TX	0.20	--
Raymondville, TX	Raymondville, TX	0.002	--
Reese AFB, TX	Reese AFB, TX	0.02	0
Richland Springs, TX	Richland Springs, TX	0.025	--
Rio Grande City, TX	Rio Grande City, TX	0.10	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Roby, TX	Roby, TX	0.06	--
Rochester, TX	Rochester, TX	0.04	--
Ropesville, TX	Ropesville, TX	0.03	--
Roscoe, TX	Roscoe, TX	0.15	--
Rotan, TX	Rotan, TX	0.12	--
Sabinal, TX	Sabinal, TX	0.08	--
San Angelo, TX	San Angelo, TX	4.8	0
San Saba, TX	San Saba, TX	0.17	--
Santa Anna, TX	Santa Anna, TX	0.10	--
Seagraves, TX	Seagraves, TX	0.19	--
Seminole, TX	Seminole, TX	0.45	--
Shallowater, TX	Shallowater, TX	0.08	--
Silverton, TX	Silverton, TX	0.09	--
Slaton, TX	Slaton, TX	0.40	--
Snyder, TX	Snyder, TX	1.50	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Sonora, TX	Sonora, TX	0.22	--
Spur, TX	Spur, TX	0.1	--
Stanton, TX	Stanton, TX	0.15	--
Stockdale, TX	Stockdale, TX	0.18	--
Sudan, TX	Sudan, TX	0.098	--
Sundown, TX	Sundown, TX	0.07	--
Sunray, TX	Sunray, TX	0.20	--
Sweetwater, TX	Sweetwater, TX	0.001	--
Tahoka, TX	Tahoka, TX	0.18	--
Taylor, TX	Taylor, TX	0.20	--
Uvalde, TX	Uvalde, TX	0.9	0
Uvaloe, TX	Uvaloe, TX	0.002	--
Van Horn, TX	Van Horn, TX	0.13	--
Wellington, TX	Wellington, TX	0.19	--
Whiteface, TX	Whiteface, TX	0.04	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg
Wilson, TX	Wilson, TX	0.03	--
Winters, TX	Winters, TX	0.80	--
Yoakum, TX	Yoakum, TX	0.42	--
Youth City, TX	Youth City, TX	0.004	--
Kaiser Steel Corp.	Sunnyside, VT	0.1	0
Ephrata, WA	Ephrata, WA	0.4	--
Quincy, WA	Quincy, WA	0.8	--
Soap Lake, WA	Soap Lake, WA	0.11	--
Walla Walla, WA	Walla Walla, WA	8.3	0
Warden, WA	Warden, WA	1.3	0
Howes Leather Co.	Frank, W.VA	0.015	--
American Stores Dairy Company	Fairwater, WI	0.4	--
Libby, McNeill & Libby	Janesville, WI	0.75	--
Spring Green,WI	Spring Green, WI	--	--

TABLE A-2 (continued)

Facility name	Location	Volume reused mgd	Unit charged for effluent $/mg
Cheyenne, WY	Cheyenne, WY	7-7-5	--
Rawlins, WY	Rawlins, WY	--	--

TABLE A-3

INVENTORY OF WASTEWATER REUSE LOCATIONS IN THE UNITED STATES

EFFLUENT USED FOR GROUNDWATER RECHARGE

Managing Agency	Location	Purpose of Recharge	MGD
U.S. Marine Corp.	Camp Pendleton, CA	. Groundwater replenishment . Salt water barrier	4
Eastern Municipal Water District	Hemet, CA	. Groundwater replenishment	2
Nassau County Department of Public Works - U.S. Geological Survey	Long Island, NY	. Groundwater replenishment . Salt water barrier	0.5
Water and Sewer Dept.	Oceanside, CA	. Treatment for reuse	6[a]
Orange County Water District	Orange County, CA	. Groundwater replenishment . Salt water barrier	15[b]
Santa Clara Valley Water District	Palo Alto, CA	. Salt water barrier . Treatment for reuse	2[c]
U.S. Water Conservation Laboratory	Phoenix, AZ	. Treatment for reuse	15[d]
City of San Clemente	San Clemente, CA	. Salt water barrier	2
Government of the Virgin Islands	St. Croix, Virgin Islands	. Groundwater replenishment	0.4

TABLE A-3 (continued)

Managing Agency	Location	Purpose of Recharge	MGD
L.A. County Flood Control District	Whittier, CA	Groundwater replenishment	25

---

[a] Operational 1975.

[b] Operational 1976.

[c] Present system temporarily provides 1 MGD for groundwater replenishment. New 6 MGD program operational 19751

TABLE A-4

INVENTORY OF WASTEWATER REUSE LOCATIONS IN THE UNITED STATES

EFFLUENT USED FOR FISH PROPAGATION AND RECREATION

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg	Comments
L.A. County Sanitation District Lancaster Plant	Los Angeles, CA	0.5	0	No swimming
Santee County Water District	San Diego, CA	1.0	0	No swimming
South Lake Tahoe, CA	S. Lake Tahoe,CA	2.7	0	
U.S. Air Force Academy	Colorado Springs, CO	1.4	0	No swimming or boating
Okolona Sewer Control District	Okolona, KY	1.0	0	No swimming or boating

TABLE A-5

INVENTORY OF WASTEWATER REUSE LOCATIONS IN THE UNITED STATES

EFFLUENT USED FOR RESEARCH AND DEVELOPMENT PURPOSES

Facility name	Location	Volume reused mgd	Unit charges for effluent $/mg	Comments
San Diego, CA	San Diego, CA	.015	0	Experimental boiler feed
Denver Board of Water Commissioners	Denver, CO	0.5	0	
Penn State University	University Park, PA	0.5	0	

APPENDIX B

WATER QUALITY REQUIREMENTS OF SELECTED WATER USERS

Table B-1 Limits of Pollutants for Irrigation Water Recommended by EPA

Table B-2 Water Quality Parameter Limits for Livestock

Table B-3 Cooling Water Quality Requirements for Makeup Water to Recirculating Systems

Table B-4 Quality Tolerances for Constituents of Industrial Boiler Feedwater

Table B-5 Quality Criteria for Wastewater Used for Recreational Purposes

Table B-6 Selected Drinking Water Quality Parameters

Table B-7 Tentative Guides for the Quality of Water Required for Fish Life

TABLE B-1

LIMITS OF POLLUTANTS FOR IRRIGATION WATER RECOMMENDED BY EPA[1]

Constituents	For Water Used Continuously On All Soils (mg/l)	For Short-Term Use[a] On Fine Textured Neutral and Alkaline Soils (mg/l)
Heavy Metals		
Aluminum	5.0	20.0
Arsenic	2.0	10.0
Beryllium	0.1	0.5
Boron	0.75	2.0
Cadmium	0.01	0.05
Chromium	0.1	1.0
Cobalt	0.05	5.0
Copper	0.2	5.0
Fluoride	2.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5	-
Manganese	0.2	10.0
Molybdenum	0.01	0.05
Nickel	0.2	2.0
Selenium	0.02	-
Bacterial		
Coliform density	1,000/100ml	
Chemical		
pH	4.5-9.0	
TDS	5,000	
Herbicides		
Dalapon	0.2 µg/l	
TCA	0.2 µg/l	
2,4-D	0.1 µg/l	

[a] "Short-term" used here means a period of time as long as 20 years.

TABLE B-2

WATER QUALITY PARAMETERS LIMITS FOR LIVESTOCK [2]

Quality Factor	Threshold Concen.[a]	Limiting Concen.[b]	EPA Acceptable Concen.
Total dissolved solids (TDS), mg/l	2,500	5,000	
Cadmium, mg/l	5		5.0
Calcium, mg/l	500	1,000[c]	
Magnesium, mg/l	250	500[c]	
Sodium, mg/l	1,000	2,000[c]	
Arsenic, mg/l	1		2.0
Bicarbonate, mg/l	500	500	
Chloride, mg/l	1,500	3,000	
Fluoride, mg/l	1	6	2
Nitrate, mg/l	200	400	100
Nitrite, mg/l	None	None	
Sulfate, mg/l	500	1,000[c]	
Range of pH	6.0-8.5	5.6-9.0	

[a] Threshold values represent concentrations at which poultry or sensitive animals might show slight effects from prolonged use of such water. Lower concentrations are of little or no concern.

[b] Limiting concentrations based on interim criteria, South Africa. Animals in lactation or production might show definite adverse reactions.

[c] Total magnesium compounds plus sodium sulfate should not exceed 50 percent of the total dissolved solids.

TABLE B-3

COOLING WATER QUALITY REQUIREMENTS FOR MAKEUP WATER TO RECIRCULATING SYSTEMS[3]

Parameter	Reference (4)	Reference (5)	Comment
Cl	500		up to 460 successfully used
TDS	500	--	up to 1,650 successfully used
Hardness ($CaCO_3$)	130	50	--
Alkalinity ($CaCO_3$)	20	--	--
pH	aar[a]	6.9-9.0	preferably 6.8-7.2
COD	75	--	preferably below 10
TSS	100	25	preferably below 10
Turbidity	--	50	preferably below 10
BOD	--	25	preferably below 5
MBAS	--	2	2 is good
NH_3	--	4	preferably below 1
PO_4	--	1	<1 is good
SiO_4	50	--	--
Al	0.1	--	--
Fe	0.5	0.5	--
Mn	0.5	--	--
Ca	50	--	--
Mg	aar	0.5	--
HCO_3	24	--	--
SO_4	200	--	--

[a] aar = accepted as received

TABLE B-4

QUALITY TOLERANCES FOR CONSTITUENTS OF INDUSTRIAL BOILER FEEDWATER [3]

Quality Parameter	Federal Water Pollution Control Administration (now EPA) Pressure Ranges, psig 0-150	150-700	700-1500
TDS, ppm	700	500	200
Suspended solids, ppm	10	5	0.0
Silica, ppm	30	10	0.7
Hardness as $CaCO_3$, ppm	20	0.0	0.0
Alkalinity, ppm	140	100	40
pH, units	8.0-10.0	8.2-10.0	8.2-9.0
Dissolved oxygen, ppm	2.5	0.007	0.007
Iron, ppm	1.0	0.30	0.05
Manganese, ppm	0.3	0.10	0.01
Aluminum, ppm	5	0.10	0.01
Bicarbonate, ppm	170	120	0.01
Chloride, ppm	NP[a]	NP	NP
Sulfate, ppm	NP	NP	NP

[a] NP - no problem at levels normally encountered.

TABLE B-5

QUALITY CRITERIA FOR WASTEWATER USED FOR RECREATIONAL PURPOSES [3]

For recreational use, general water characteristics of concern include the following:

- Dissolved oxygen concentrations must always be above levels required to support game fish. Therefore, the organic strength, e.g., BOD, of the effluent must not exert an oxygen demand which lowers dissolved oxygen concentrations below acceptable levels. In addition, dissolved oxygen levels can be affected seriously by heavy algae growth or formation of an ice covering.
- Nutrients, e.g., nitrogen and phosphate compounds, stimulate unaesthetic algal growth and accelerate eutrophication.
- Ammonia in small concentrations can be very toxic to fish. The level of toxicity depends upon other water characteristics, including pH, dissolved oxygen, and carbon dioxide concentrations.
- Fecal coliforms are indicative of the presence of pathogenic bacteria and viruses which can cause illness to persons coming in contact with the water.

TABLE B-6

SELECTED DRINKING WATER QUALITY PARAMETERS[3]

	Regulatory Agency		
	WHO		USPHS
Parameter, mg/l	Acceptable	Allowable	
pH	7.0-8.5	6.5-9.2	6.0-8.5
Color	5	50	15
Turbidity	5	25	5
TDS	500	1,500	500
Sulfates	200	400	250
Chlorides	200	600	250
Nitrates	--	45	45
Ammonium Nitrogen	0.5	--	--
Kjeldahl Nitrogen	1.0	--	--
COD	10	--	--
BOD	6	--	--
DO	--	--	4-7.5
ABS	0.5	1.0	0.5
Coliform	--	--	1

TABLE B-7

TENTATIVE GUIDES FOR THE QUALITY OF WATER REQUIRED FOR FISH LIFE [6]

Determination	Threshold concentration[a] Fresh water
Total dissolved solids (TDS), mg/l	2,000[b]
Electrical conductivity, umhos/cm @ 25°C	3,000[b]
Temperature, maximum °C	34
Maximum for salmonoid fish	23
Range of pH	6.5-8.5
Dissolved oxygen (D.O.), minimum mg/l	5.0[c]
Flotable oil and grease, mg/l	0
Emulsified oil and grease, mg/l	10[b]
Detergent, ABS, mg/l	2.0
Ammonia (free), mg/l	0.5[b]
Arsenic, mg/l	1.0[b]
Barium, mg/l	5.0[b]
Cadmium, mg/l	0.01[b]
Carbon dioxide (free), mg/l	1.0
Chlorine (free), mg/l	0.02
Chromium, hexavalent, mg/l	0.05[b]
Copper, mg/l	0.02[b]
Cyanide, mg/l	0.02[b]
Fluoride, mg/l	1.5[b]
Lead, mg/l	0.1[b]
Mercury, mg/l	0.01
Nickel, mg/l	0.05[b]
Phenolic compounds, as phenol, mg/l	1.0
Silver, mg/l	0.01
Sulfide, dissolved, mg/l	0.5[b]
Zinc, mg/l	0.1

[a] Threshold concentration is value that normally might not be deleterious to fish life. Waters that do not exceed these values should be suitable habitats for mixed fauna and flora.

[b] Values not to be exceeded more than 20 percent of any 20 consecutive samples, nor in any 3 consecutive samples. Other values should never be exceeded. Frequency of sampling should be specified.

[c] Dissolved oxygen concentrations should not fall below 5.0 mg/liter more than 20 percent of the time and never below 2.0 mg/liter. (Note: Recent data indicate also that rate of change of oxygen tension is an important factor, and that diurnal changes in D.O. may, in sewage-polluted water, render the value of 5.0 of questionable merit.)

APPENDIX B

REFERENCES

1. Water Quality Criteria. Draft Report, Environmental Protection Agency, Washington, D.C., 1973.

2. Camp, Thomas R. Water and Its Impurities. Reinhold Book Corporation, 1963.

3. Schmidt, C. and E. Clements. Demonstrated Technology and Research Needs for Reuse of Municipal Wastewater. Environmental Protection Agency, Washington, D.C. Contract No. 68-03-0148. 1974.

4. Federal Water Pollution Control Administration. Water Quality Criteria. April 1968.

5. Petrasek, Albert C., S.E. Esmond, and H. Wolf. Municipal Wastewater Qualities and Industrial Requirements. (Presented at ASCHE meeting. Washington, D.C. April 1973.)

6. McGaughy, P.H. Engineering Management of Water Quality. New York, McGraw Hill, 1968.

APPENDIX C

VALUES OF THE ENGINEERING NEWS-RECORD (ENR) CONSTRUCTION COST INDEX 1966-1974

Year	ENR Construction Cost Index
1966	1019
1967	1070
1968	1154
1969	1270
1970	1380
1971	1571
1972	1752
1973	1900
1974[a]	2014

[a] Through June 1974.

APPENDIX D

SAMPLE COST CURVES FOR ESTIMATING CAPITAL AND OPERATING AND MAINTENANCE EXPENDITURES OF WATER SUPPLY AND WASTEWATER TREATMENT FACILITIES

Basic to all economic analyses is an understanding of the costs involved for each alternative course of action. Presented in this appendix are examples of cost curves which can be used to approximate the capital and operating and maintenance costs associated with various types of water supply and wastewater treatment facilities, as follows:

- Pumping stations
- Storage reservoirs
- Water treatment facilities
- Wastewater treatment facilities
- Demineralization facilities

The cost information presented herein is intended to illustrate the type of data that is available for use in estimating costs. More detailed information on water supply and wastewater treatment costs, such as found in References 1 through 5 and 7, should be used for cost-effectiveness analyses.

Capital Costs

Capital cost data provided in this appendix are summarized from the literature.[1,2,3,4,5,6,7] All costs are adjusted to an ENR Construction Cost Index of 2000, which is representative for mid-1974. Unit prices include contractor's overhead and profit, but do not include engineering, construction contingencies, rights-of-way, land acquisition, or legal costs.

Pumping Stations. Construction costs for both booster pumping stations and wastewater effluent pumping facilities are shown on Figure D-1.

Booster station costs are presented for average capacity in million gallons per day (mgd) for different total dynamic pumping heads (TDH). The costs account for enclosed stations with architectural and landscaping treatment suitable for residential areas.

Costs of wastewater effluent pumping facilities are based on units adjoined to existing chlorine contact chambers. Because additional area and enclosed structures are not required for these facilities, the costs are less than for booster stations. The costs presented are for peak capacity and should be increased by 25 percent for each additional 125 feet of pumping head greater than 125 feet.

Storage Reservoirs. Costs for storage reservoirs include expenditures for foundations, site preparation, inlet and outlet piping with appropriate controls, and overflow works.

Figure D-2 shows the construction costs used in this report for both steel ground level reservoirs and lined and covered excavated reservoirs as a function of storage capacity. Both types of reservoirs would be suitable for storing wastewater effluent prior to reuse, as well as for fresh water storage. Wastewater can also be stored in less costly unlined lagoons under suitable condition.

Water and Wastewater Treatment Facilities. Figure D-3 shows the estimated construction costs for both water and wastewater treatment facilities as a function of average daily plant capacity. These curves agglomerate costs for the various unit processes utilized in each type of treatment system, as explained below.

Total costs for surface water treatment include costs for coagulation, sedimentation, filtration, and disinfection. Costs for softening are not included. Groundwater treatment costs include facilities for the reduction of iron and manganese to drinking water standards.

Secondary wastewater facilities include conventional primary treatment and activated sludge treatment, plus disinfection. Processes involved in tertiary treatment include primary and activated sludge treatment, nitrification and denitrification, filtration, activated carbon absorption, and disinfection.

The developed costs are based on initial construction of units to accommodate a given average daily capacity with provision for enlargement up to three times the initial capacity. Initial construction includes inlet structures and channels, major pipelines, operation and maintenance facilities, and other basic components. Enlargement costs provide for additional construction necessary to increase the plant capacity. Enlargement costs are estimated as 80 percent of initial construction costs.

Demineralization Facilities. Estimated costs of demineralization of groundwater are presented in Figure D-4.

These costs are based on ocean water desalting by distillation, and groundwater and wastewater demineralization by either ion exchange or reverse osmosis. Construction costs for ocean water desalination are considerably higher than for groundwater or wastewater, primarily due to the much higher removal efficiencies required.

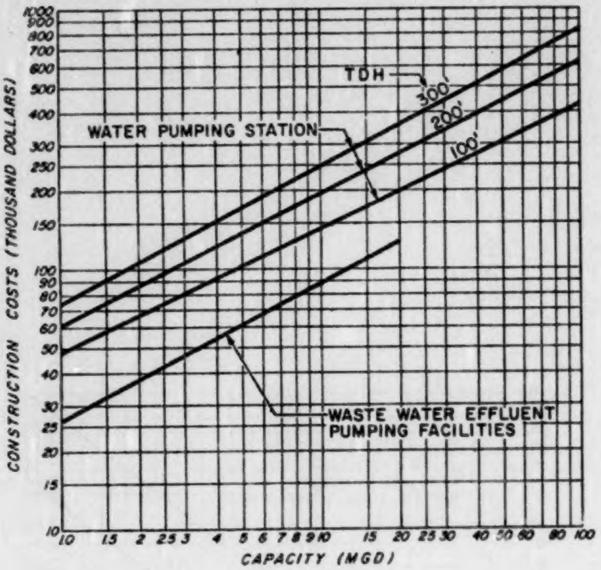


Figure D-1. Construction Cost of Pumping Facilities (ENR=2000)[6]

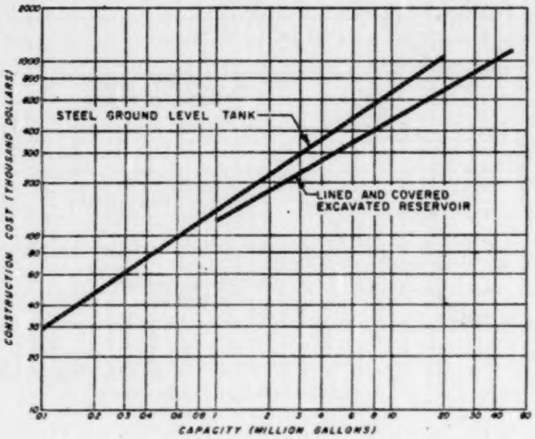


Figure D-2. Construction Cost of Reservoirs (ENR=2000)[6]

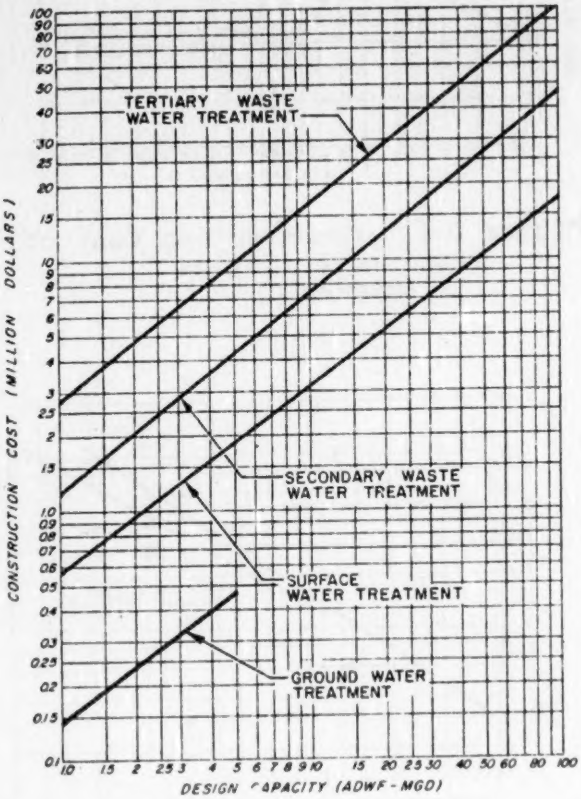


Figure D-3. Construction Cost of Treatment Facilities (ENR=2000)[6]

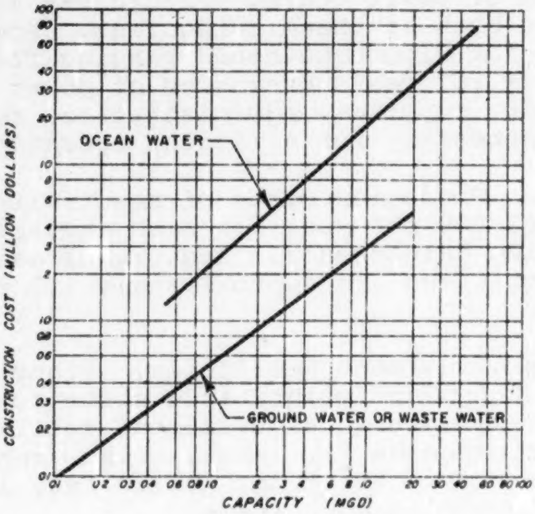


Figure D-4. Construction Cost of Demineralization (ENR=2000)[6]

Operation and Maintenance Costs

Economic evaluation of alternative projects requires consideration of operation and maintenance as well as capital costs. Operation and maintenance costs include expenditures for labor, repairs, power, chemical, supplies, administration, and additional costs which vary from project to project. Operating costs presented herein are also based on an ENR Construction Cost Index of 2000.

Pumping Facilities. Total operation and maintenance costs for pumping facilities consist of power costs for the various flows and pumping heads, and other normal operating costs which are exclusive of power costs. Figure D-5 indicates operating costs for both of these categories. Power costs are based on rates for discharge heads ranging from 25 to 400 feet. The curve for costs exclusive of power includes allowances for labor, supplies, administration, replacement parts, and repairs necessary for efficient operation.

Storage Reservoirs. Operation costs of reservoirs are estimated to be about $1,000 per year for each installation to cover minimum routine maintenance. Additional maintenance costs for these facilities are approximately 1.2 percent of construction costs.

Water and Wastewater Treatment Facilities. Figure D-6 shows representative operating and maintenance costs for water and secondary and tertiary wastewater treatment facilities. Total costs include expenses for labor, power, repairs, chemicals, supplies, administration, monitoring, laboratory control, and other miscellaneous items.

Demineralization Facilities. Figure D-7 indicates the costs anticipated for ocean water desalting by distillation and groundwater and wastewater demineralization by either ion exchange or reverse osmosis processes. Desalting technology is presently developing so operation and maintenance costs are relatively high when compared with other water and wastewater treatment processes.

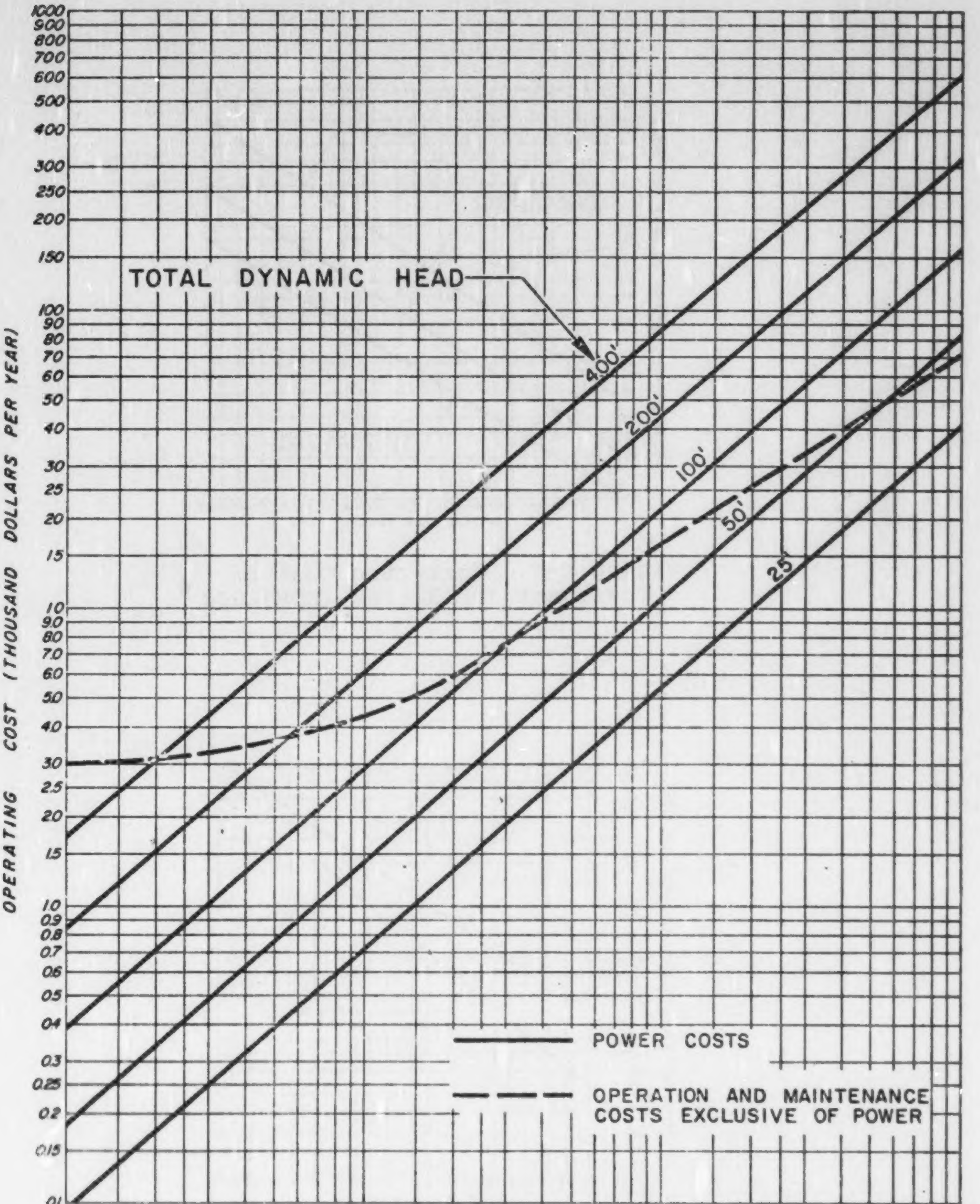


Figure D-5. Operating Cost of Pumping Facilities (ENR=2000)[6]

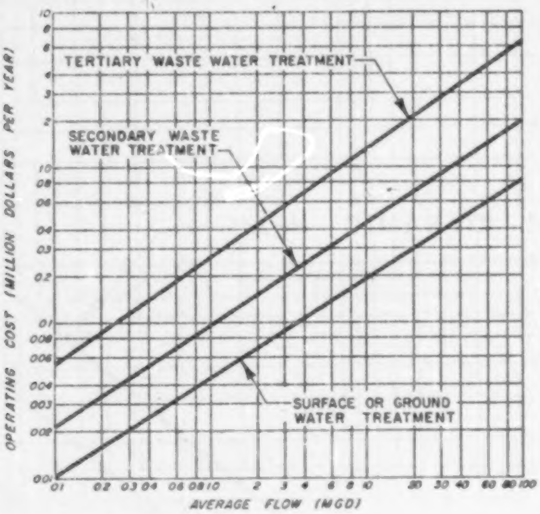


Figure D-6. Operating Cost of Treatment Facilities (ENR=2000)[6]

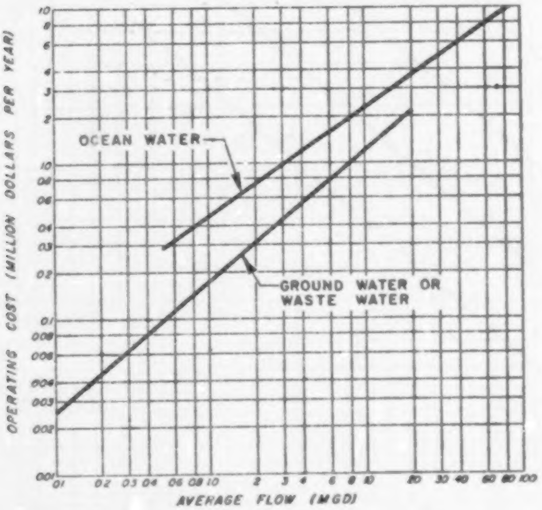


Figure D-7. Operating Cost of Demineralization Facilities (ENR=2000)[6]

APPENDIX D

REFERENCES

1. Blecker, Herbert G., and Theodore W . Cadman. Capital and Operating Costs of Pollution Control Equipment Modules, Vols. I and II. Environmental Protection Agency, Washington, D.C., July 1973.

2. Eilers, Richard G. Wastewater Treatment Plant Cost Estimating Program. Environmental Protection Agency, Washington, D.C., April 1971.

3. Patterson, W.L., and R.F. Banker. Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities. Environmental Protection Agency, Washington, D.C., October 1971.

4. Smith, Robert A. A Compilation of Cost Information for Conventional and Advanced Wastewater Treatment Plant and Processes. Environmental Protection Agency, Washington, D.C., December 1967.

5. Smith, Robert A. Costs of Wastewater Renovation. Environmental Protection Agency, Washington, D.C., November 1971.

6. Toups Corporation. Water Resources Management Study, South Coast-Santa Barbara County. July 1974.

7. Watson, I.C. Manual for Calculation of Conventional Water Treatment Costs. Department of the Interior, Washington, D.C., March 1972.

APPENDIX E

7% COMPOUND INTEREST FACTORS

n	SINGLE PAYMENT		UNIFORM SERIES				n
	Compound Amount Factor caf′	Present Worth Factor pwf′	Sinking Fund Factor sff	Capital Recovery Factor crf	Compound Amount Factor caf	Present Worth Factor pwf	
	Given *P* To find *S* $(1+i)^n$	Given *S* To find *P* $\frac{1}{(1+i)^n}$	Given *S* To find *R* $\frac{i}{(1+i)^n-1}$	Given *P* To find *R* $\frac{i(1+i)^n}{(1+i)^n-1}$	Given *R* To find *S* $\frac{(1+i)^n-1}{i}$	Given *R* To find *P* $\frac{(1+i)^n-1}{i(1+i)^n}$	
1	1.070	0.9346	1.00000	1.07000	1.000	0.935	1
2	1.145	0.8734	0.48309	0.55309	2.070	1.808	2
3	1.225	0.8163	0.31105	0.38105	3.215	2.624	3
4	1.311	0.7629	0.22523	0.29523	4.440	3.387	4
5	1.403	0.7130	0.17389	0.24389	5.751	4.100	5
6	1.501	0.6663	0.13980	0.20980	7.153	4.767	6
7	1.606	0.6227	0.11555	0.18555	8.654	5.389	7
8	1.718	0.5820	0.09747	0.16747	10.260	5.971	8
9	1.838	0.5439	0.08349	0.15349	11.978	6.515	9
10	1.967	0.5083	0.07238	0.14238	13.816	7.024	10
11	2.105	0.4751	0.06336	0.13336	15.784	7.499	11
12	2.252	0.4440	0.05590	0.12590	17.888	7.943	12
13	2.410	0.4150	0.04965	0.11965	20.141	8.358	13
14	2.579	0.3878	0.04434	0.11434	22.550	8.745	14
15	2.759	0.3624	0.03979	0.10979	25.129	9.108	15
16	2.952	0.3387	0.03586	0.10586	27.888	9.447	16
17	3.159	0.3166	0.03243	0.10243	30.840	9.763	17
18	3.380	0.2959	0.02941	0.09941	33.999	10.059	18
19	3.617	0.2765	0.02675	0.09675	37.379	10.336	19
20	3.870	0.2584	0.02439	0.09439	40.995	10.594	20
21	4.141	0.2415	0.02229	0.09229	44.865	10.836	21
22	4.430	0.2257	0.02041	0.09041	49.006	11.061	22
23	4.741	0.2109	0.01871	0.08871	53.436	11.272	23
24	5.072	0.1971	0.01719	0.08719	58.177	11.469	24
25	5.427	0.1842	0.01581	0.08581	63.249	11.654	25
26	5.807	0.1722	0.01456	0.08456	68.676	11.826	26
27	6.214	0.1609	0.01343	0.08343	74.484	11.987	27
28	6.649	0.1504	0.01239	0.08239	80.698	12.137	28
29	7.114	0.1406	0.01145	0.08145	87.347	12.278	29
30	7.612	0.1314	0.01059	0.08059	94.461	12.409	30
31	8.145	0.1228	0.00980	0.07980	102.073	12.532	31
32	8.715	0.1147	0.00907	0.07907	110.218	12.647	32
33	9.325	0.1072	0.00841	0.07841	118.933	12.754	33
34	9.978	0.1002	0.00780	0.07780	128.259	12.854	34
35	10.677	0.0937	0.00723	0.07723	138.237	12.948	35
40	14.974	0.0668	0.00501	0.07501	199.635	13.332	40
45	21.002	0.0476	0.00350	0.07350	285.749	13.606	45
50	29.457	0.0339	0.00246	0.07246	406.529	13.801	50
55	41.315	0.0242	0.00174	0.07174	575.929	13.940	55
60	57.946	0.0173	0.00123	0.07123	813.520	14.039	60
65	81.273	0.0123	0.00087	0.07087	1146.755	14.110	65
70	113.989	0.0088	0.00062	0.07062	1614.134	14.160	70
75	159.876	0.0063	0.00044	0.07044	2269.657	14.196	75
80	224.234	0.0045	0.00031	0.07031	3189.063	14.222	80
85	314.500	0.0032	0.00022	0.07022	4478.576	14.240	85
90	441.103	0.0023	0.00016	0.07016	6287.185	14.253	90
95	618.670	0.0016	0.00011	0.07011	8823.854	14.263	95
100	867.716	0.0012	0.00008	0.07008	12381.662	14.269	100

Reference: Grant, Eugene L. and W. Grant Ireson. Principles of Engineering Economy, New York, Roland Press Company, 1960.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1976— 623-639/533